Joint Effect of East Asia–Pacific and Eurasian Teleconnections on the Summer Precipitation in North Asia

Po HU1, Guolin FENG2,4, Muhammad Mubashar DOGAR3, Jianbo CHENG5, and Zhiqiang GONG2*

1 Hubei Key Laboratory for Heavy Rain Monitoring and Warning Research, Institute of Heavy Rain, China Meteorological Administration, Wuhan 430205, China
2 National Climate Center, China Meteorological Administration, Beijing 100081, China
3 Global Change Impact Studies Centre (GCISC), Ministry of Climate Change, Islamabad 44000, Pakistan
4 College of Physical Science and Technology, Yangzhou University, Yangzhou 225002, China
5 College of Atmospheric Sciences, Lanzhou University, Lanzhou 730000, China

(Received October 18, 2019; in final form February 19, 2020)

ABSTRACT

The East Asia–Pacific (EAP) and Eurasian (EU) teleconnections are independent of each other on the seasonal timescale (with a correlation coefficient of only 0.03). But they may occur concurrently with consistent or opposite phases. This paper investigates their synergistic effect on the summer precipitation in North Asia. Based on the signs/phases of EAP and EU indices, the EAP and EU teleconnection anomalies occur in four cases: (I) positive EAP + positive EU, (II) negative EAP + negative EU, (III) positive EAP + negative EU, and (IV) negative EAP + positive EU. Further analyses show that these four configurations of EAP and EU anomalies are coherently related to different atmospheric circulations over the midlatitude Eurasian continent, leading to different summer precipitation modes in North Asia. Category I (II) corresponds to a zonal tripole structure of the geopotential height at 500 hPa over eastern Europe and the Sea of Japan, leading to less (more) than normal precipitation in eastern Europe, Japan, and the surrounding areas, and more (less) precipitation from central China to Lake Baikal and eastern Russia. Category III (IV) corresponds to a meridional dipole structure of the geopotential height at 500 hPa over North Asia, leading to more (less) precipitation in the northern North Asia and less (more) precipitation in most of the southern North Asia. Independent analysis reveals that the EAP teleconnection itself is positively correlated with the precipitation in the region between the eastern part of Lake Baikal and Okhotsk Sea, and negatively correlated with the precipitation in the region between Northeast China and Japan. Coincidently, the EU pattern and precipitation have negative correlations in Ural Mountain and Okhotsk Sea areas and positive correlations in the Lake Baikal area. The respective relations of EAP and EU with the summer precipitation in North Asia suggest that the EAP northern lobe overlapped with the EU central and eastern lobes could extend the geopotential anomalies over Lake Baikal to Russian Far East, creating an EAP–EU synergistic effect on the summer precipitation in North Asia.

Key words: East Asia–Pacific (EAP) teleconnection, Eurasian (EU) teleconnection, synergistic effect, precipitation

Citation: Hu, P., G. L. Feng, M. M. Dogar, et al., 2020: Joint effect of East Asia–Pacific and Eurasian teleconnections on the summer precipitation in North Asia. J. Meteor. Res., 34(3), 559–574, doi: 10.1007/s13351-020-9112-z.

1. Introduction

While analyzing the relationship between the equatorial Pacific sea surface temperature (SST) anomaly and Northeast Pacific westerlies circulation, Bjerknes (1969) found that the correlations between them in winters of 1957–1958, 1963–1964, and 1965–1966 are similar, which are called teleconnections. With further studies along the line, the correlation between the anomalous circulations over two different regions is generally defined as a teleconnection. It has been revealed that atmospheric teleconnection patterns play important roles in influencing global climate anomalies, which have been highly valued by many meteorologists in previous studies (Fan and Wang, 2004; Li et al., 2008; Wang et al., 2012; Grotjahn et al., 2016; Lin and Lu, 2016; Dogar et al., 2017).

Supported by the National Key Research and Development Program of China (2018YFA0606301 and 2018YFC1507702) and National Natural Science Foundation of China (41875100, 41575082, and 41530531).
*Corresponding author: gongzq@cma.gov.cn.

©The Chinese Meteorological Society and Springer-Verlag Berlin Heidelberg 2020
The East Asia–Pacific (EAP) teleconnection, also called the Pacific–Japan (PJ) teleconnection pattern, was first proposed by Huang and Li (1987) and Nitta (1987). When the temperature of the western Pacific warm pool is low, weakened convective activity occurs over the Philippines and the Maritime Continent, leading to a “+ − −” EAP teleconnection pattern, with more precipitation in the Yangtze–Huaihe River basin, Korean Peninsula, and Japan area, and vice versa. Subsequently, the EAP index was defined based on the EAP teleconnection pattern, which has a strong relationship with the summer climate of the East Asian (EA) region, as studied in detail by Huang et al. (2004). Huang et al. (2007) revealed that the EAP meridional tripole pattern from the tropics poleward to the extratropics is mainly triggered by anomalies of the convective activity over the tropical western Pacific, which can be found on different timescales. Gong et al. (2017, 2018a) pointed out that the formation of the EAP pattern is closely related to the heating of the tropical western and eastern Pacific. In addition, Bueh et al. (2008) argued that the maintenance and development of the EAP teleconnection pattern is closely related to the energy that is propagated downstream through flux waves in the middle and high latitudes of the Eurasian (EU) continent. Yang et al. (2010) showed that the EAP teleconnection with the “− + − (+ − +)” pattern can promote (inhibit) the northward expansion of the western Pacific subtropical high (WPSH), thus affecting the northern (southern) part of the Huai River valley. Li et al. (2016) further presented a close relationship between the low-frequency oscillation of the EAP teleconnection and the persistent rainstorm in the lower reaches of the Yangtze–Huaihe River. Srinivas et al. (2018) showed that anticyclone and low-level circulation anomalies in the western Pacific increase precipitation in southern and northern India, confirming the association between the EAP/PJ teleconnection and the Indian monsoon precipitation. Wang et al. (2018) found that the EAP teleconnection has a significant relationship with the wave activity flux, which has an effect on the extreme precipitation in the middle and lower reaches of the Yangtze River under the interaction of low, medium, and high levels.

The EU teleconnection pattern is one of the five important teleconnection wave trains propagating from west to east over the EU continent. Wallace and Gutzler (1981) proposed that this is obvious from the 500-hPa geopotential height field in the Northern Hemisphere. The EU teleconnection pattern mainly reflects an inverse correlation between the geopotential height over western Europe and that in Siberia, but it shows a positive correlation with Northeast China and Japan. Lee et al. (2005) found that the summer EU teleconnection is closely correlated with precipitation in the tropical region. When the EU index is positive, the surface temperature in South China is low (Zhou W. et al., 2009), and there is more rainfall in Tokyo (Tachibana et al., 2007). Barnston and Livezey (1987) studied the decomposed EU teleconnection patterns, i.e., EU teleconnection I (EUI) and II (EUII). Liu et al. (2014) compared the spatial features, temporal variability, and difference of the winter climate among the three EU teleconnections defined by Wallace and Gutzler (1981). The EU teleconnection pattern has a significant influence on the plateau and ocean subtropical jets, which in turn affect the winter temperature and precipitation in China (Wang and Zhang, 2015). Hingmire et al. (2019) confirmed that the positive (height excess over Siberia) EU teleconnection phase favors the occurrence of widespread fog in the Indo-Gangetic region.

Previous studies have shown that the EU teleconnection has a significant impact on the climate of Eurasia, especially that of EA (Wallace and Gutzler, 1981; Takaya and Nakamura, 2013; Wang and Chen, 2014). The EAP teleconnection also has a significant impact on the EA climate (Huang and Sun, 1992; Ueda et al., 1995; Nitta and Hu, 1996; Chen and Zhai, 2015). Nitta et al. (1996) showed that the variation of the summer precipitation and temperature in China are relevant to the influences of both EAP and EU patterns. The zonal EU teleconnection along the jet stream and the EAP teleconnection along the meridional direction are two important teleconnection lines in summer, which are interactive with each other over North Asia (NA) and EA. Lu et al. (2006) and Lu (2004) demonstrated the seasonal differences in the EAP teleconnection between early summer (June) and late summer (August); also, the EAP teleconnection is affected by the midlatitude teleconnection. Therefore, the wave–flow interaction in the mid–high latitudes in Eurasia and the interaction of the meridional and zonal teleconnections may have a joint influence on the climate anomalies over EA, especially in NA. Ogawara and Kawamura (2007, 2008) defined the mid–high-latitude teleconnection as the West Asia–Japan (WJ) and Europe–Japan (EJ) patterns, and found that the WJ or EJ pattern and PJ teleconnection pattern were inter-configured, with high-frequency and low-frequency components, affecting the EA surface temperature and summer monsoon circulation. The 10–30-day variability of summer precipitation over southeastern China during the period of 1979–2015 (Li and Mao, 2019) and the devastating floods over the Yangtze River basin during 1998 (Li and Mao, 2018) were both affected by the Rossby wave that propagated to EA at mid–high latit-
udes in the upper troposphere through the vorticity advection; meanwhile, the EAP region triggers vertical mechanisms to further enhance the strong updraft (downdraft) over the south of the middle and lower reaches of the Yangtze River valley. Chen et al. (2019) pointed out that the persistent precipitation extremes in the Yangtze River valley have the most direct relationship with the EAP teleconnection, whereas the EU and SR (Silk-Road teleconnection) types need to be exerted via their liaison with the EAP teleconnection. Previous studies mostly focus on the effects of climate caused by a single teleconnection, and few studies concentrate on the synergistic effect of EU and EAP teleconnections on the climate anomalies in NA as well as the mechanism for the interaction between these two teleconnections.

The western and middle parts of NA contain the main livestock bases, and the eastern part of NA contains the main agriculture bases and commercial centers of the Asian region. The climate in NA is affected by both the mid–high-latitude dry cold airflow and the low-latitude warm humid airflow. The EAP teleconnection mainly reflects the changes of the meridional circulation system, whereas the EU teleconnection denotes the eastward propagation of the circulation wave originated from North Atlantic. The EU zonal wave transported by the Rossby waves can expand from North Atlantic to EA. The intersection of the EAP and EU teleconnections are mainly overlapped in the NA region. Therefore, it is necessary to study the joint effect of the EAP–EU teleconnection on affecting the precipitation in NA, which may be of great help for understanding the flood and drought mechanisms over this region.

Based on the above discussion, an in-depth study on the EAP–EU co-action will help us better understand the causes of precipitation anomalies in EA and NA. Therefore, this paper will analyze the relationship between the EAP and EU teleconnections, explore their co-action on the climate anomalies over NA, and briefly discuss the mechanism of the co-action from the atmospheric processes. The rest of this paper is organized as follows: A description of the study area, data, and methodology is presented in Section 2; main results are provided in Section 3; and conclusions are given in Section 4.

2. Study area and data

In this study, NA is defined as the region 30°–70°N, 70°–160°E. The following datasets are applied: (1) the Global Precipitation Climatology Project (GPCP) monthly precipitation observation dataset, which is used for validation of the summer (June, July, and August) precipitation from 1979 to 2015; and (2) the NCEP–NCAR monthly reanalysis dataset, which includes the variables of surface pressure, zonal and meridional winds, and specific humidity on a horizontal resolution of 2.5° × 2.5°.

The EAP index is defined as below (Huang, 2004):

\[
I_{EAP} = -\frac{1}{4}Z^*(20°N,125°E) + \frac{1}{2}Z^*(40°N,125°E) - \frac{1}{4}Z^*(60°N,125°E) \tag{1}
\]

According to the studies of Wallace and Gutzler (1981) and Wakabayashi and Kawamura (2004), the EU index is defined as below:

\[
I_{EU} = -\frac{1}{4}Z^*(55°N,20°E) + \frac{1}{2}Z^*(55°N,75°E) - \frac{1}{4}Z^*(52.5°N,110°E) \tag{2}
\]

In Eqs. (1) and (2), \(Z\) represents the normalized monthly average geopotential height anomaly at 500 hPa.

3. Results

3.1 Summer precipitation patterns under EAP–EU configurations

According to Eqs. (1) and (2), the normalized indices of EAP and EU during the period of 1948–2015 are presented in Fig. 1. It is evident that both EAP and EU teleconnection indices show obvious interannual variations. The EU index also exhibits interdecadal variability as it changes from its most positive phase before the early 1990s to its most negative phase after the early 1990s. The 30-yr sliding correlation between the EAP and EU indices has a rapid decrease around 1980 (Figs. 1b, c). The correlation coefficient between the EAP and EU indices is 0.03 for the period of 1979–2015 and 0.35 for 1948–1978, indicating that EAP and EU teleconnection patterns are independent of each other after 1979. That is to say, the relationship between the two teleconnections has an adjustment around 1979. Therefore, it is necessary to study the EAP–EU joint effects on summer precipitation in EA and NA before and after 1979, respectively. This study mainly reveals the configurations of EAP and EU teleconnection anomalies and their corresponding impact on summer precipitation in NA during the period of 1979–2015, which matches well with the period of the GPCP dataset.

To facilitate further analysis, the configurations of EAP and EU according to signs of their indices are divided into four categories. In Category I (II), the EAP and EU index anomalies are in the same phase (the same
positive or negative anomalies); while in Category III (IV), EAP and EU index anomalies are in the opposite phase [the EAP index being a positive (negative) phase and the EU index being a negative (positive) phase]. In order to better express the differences between the EAP and EU indices in the four categories and to ensure that the number of years is as large as possible, we have chosen the absolute values of the EAP and EU indices to be larger than 0.3-time standard (std) deviation as the selection criterion. Table 1 illustrates that, the EAP and EU indices are in the positive phase for six years (Category I), the EAP and EU indices are in the negative phase for six years (Category II), and the EAP and EU indices are in the opposite phase for the remaining years (Category III and IV).

Fig. 1. The (a) time series (black solid and dashed lines are the 0.7 and 0.3 standard deviations, respectively) and (b) scatter diagram of EAP and EU standardized indices. (c) The sliding correlation coefficient between EAP and EU indices with a 30-yr window and a 1-yr moving step.
nine years (Category II), the EAP index is in the positive phase and the EU index is in the negative phase for six years (Category III), and the EU index is in the positive phase and the EAP index is in the negative phase for three years (Category IV). The EAP and EU indices are in the same phase for 15 years (Categories I and II), and those in the opposite phase for 9 years (Categories III and IV). This suggests that the EAP and EU indices are more likely to occur when they are both active in the same phase. In order to better study the role of EAP and EU in affecting the EA/NA climate, the characteristics of precipitation and circulation under the four categories are analyzed below.

Figure 2 gives composite anomalies of summer precipitation in NA corresponding to different EAP–EU configurations. For Category I configuration, when the EAP and EU indices are both positive, the summer precipitation anomaly in NA is mainly distributed with a “− + −” structure from northwest to southeast. Less precipitation is seen over the Ural Mountain area, coastal East China to Japan, and surrounding sea areas; whereas more precipitation is observed in the regions from central China to the east of Baikal Lake and Russian Far East (Fig. 2a). Meanwhile, precipitation anomalies in northern NA (50°–70°N, 120°–160°E) are characterized by an east–west reverse-phase structure and a north–south reverse-phase distribution in eastern NA (30°–70°N, 120°–160°E). For Category II configuration, when both the EAP and EU teleconnections are in negative phases (Fig. 2b), precipitation over the EU continent exhibits the opposite spatial structure to that presented in Fig. 2a. Positive anomalies are mainly concentrated in the Ural Mountain area and Japan and its surrounding sea areas, while negative anomalies are seen in central China to Mongolia and eastern Russia. The west–east pattern in northern NA and the north–south pattern in eastern NA are also observed in Fig. 2b.

For Category III configuration, when the EAP index is positive and the EU index is negative, compared with the spatial distribution of Category I, the NA summer precipitation is mainly characterized by a “+ −” dipole distribution from north to south (Fig. 2c). The west–east pattern of the precipitation anomaly in northern NA has changed to a zonally consistent structure, whereas the north–south

| Type | \( t_{EAP} \) | \( t_{EU} \) | \( 0.3 \) std | \( 0.5 \) std | \( 0.7 \) std |
|------|------------|------------|-------------|-------------|-------------|
| I    | +         | +         | 1981, 1982, 1984, 1988, 1989, 2012 | 1981, 1989 | 1981 |
| II   | −         | −         | 1980, 1986, 1991, 1992, 2001, 2002, 2009, 2011, 2015 | 1980, 1986, 1991, 1992, 2001, 2002, 2009, 2015 | 1986, 1992, 2002, 2015 |
| III  | +         | −         | 1994, 1995, 1997, 2000, 2007, 2010 | 1994, 1997, 2007, 2010 | 2007, 2010 |
| IV   | −         | +         | 1993, 1998, 2003 | 1993, 1998, 2003 | 1993, 1998, 2003 |

Fig. 2. Horizontal distributions of the percentage of summer precipitation anomalies (color shaded; %) over North Asia for different EAP–EU configurations: (a) EAP(+)EU(+), (b) EAP(−)/EU(−), (c) EAP(+)/EU(−), and (d) EAP(−)/EU(+). Dotted areas indicate the 90% confidence level.
opposite phase feature is maintained in eastern NA. For Category IV configuration, when the EAP index is negative and the EU index is positive (Fig. 2d), the precipitation anomalies in the northern EU region (50°–70°N, 70°–160°E) are significantly less than normal, whereas the majority part of precipitation in the southern NA (30°–50°N, 70°–160°E) is more than normal, showing a “− +” dipole pattern in the meridional direction. Summer precipitation patterns corresponding to Categories I and II of the EAP–EU configuration can also be found in the first and second modes of the empirical orthogonal function (EOF) in the summer precipitation over NA (Gong et al., 2017). Therefore, the spatial distributions of NA summer precipitation are obviously different from each other for the two types of EAP–EU configuration, which calls for further study on the EAP–EU co-action through the atmospheric composite analysis.

To further reveal the association of the EAP–EU configuration with the NA summer precipitation pattern, two EOF leading zonal modes for summer precipitation anomalies are presented in Fig. 3. A notable feature of EOF1 (Fig. 3a) is the north-dry and south-wet pattern, with major positive anomalies located to the northwest of Baikal Lake and Okhotsk Sea, whereas a rainy belt dominates the region between 30°N and 50°N from west to east. The EOF1 has a very similar spatial feature to the summer precipitation anomaly distribution of Category IV of the EAP–EU configuration (Fig. 2d). The spatial pattern EOF2 (Fig. 3b) shows a northwest–southeast wave structure. Two positive lobes are respectively distributed to the west of Baikal Lake and Japan and its offshore area, whereas two negative lobes are respectively located in North China and Russian Far East. The spatial pattern of EOF2 is quite similar to the summer precipitation anomaly distribution of Category II of the EAP–EU configuration (Fig. 2b). Therefore, the EAP–EU configuration associated patterns revealed in Fig. 2 can reflect the major spatial characteristics of summer precipitation anomalies in NA.

When the EAP and EU indices are both positive, composite anomalies of the 500-hPa geopotential height exhibit a “+ − +” tripole wave train from northwest to southeast NA. The Ural Mountain area, Northeast China, and Japan are all controlled by positive anomalies, whereas negative anomalies dominate the Baikal Lake area (Fig. 4a). The coupled anticyclonic and cyclonic anomalies are also observed in both 850- and 200-hPa wind fields (Fig. 5a), showing that the wavelike pattern has an equivalent barotropic structure in the vertical direction. Meanwhile, the 500-hPa geopotential height field in northern NA shows zonal opposite phase characteristics; and in eastern NA, it shows the meridional opposite phase. According to the equation (Chen and Huang, 2012), anomalies of the 500-hPa geopotential height and wind fields may cause downward motion over the Ural Mountain area, Northeast China, and Japan, as well as upward motion over the Baikal Lake area, which can lead to the precipitation anomaly structure presented in Fig. 1a. The tripole wavelike pattern is similar to the Europe–China (EC) teleconnection pattern defined by Chen and Huang (2012), which propagates along an arc path (Hoskins and Karoly, 1981). When the EAP and EU teleconnections are both in negative phases, atmospheric circulations at 200, 500, and 850 hPa (Figs. 4b, 5b) show opposite anomalous phase distributions to those under the EAP–EU positive phases (Figs. 4a, 5a).

When the EAP index is positive and the EU index is negative, a “− +” dipole distribution is observed from north to south in the 500-hPa geopotential height field. Most parts of Russia are controlled by negative anomalies (Fig. 4c) and anticyclonic wind anomalies at both low and high levels (Fig. 5c), whereas the Baikal Lake area to Northeast China and Japan are dominated by positive height anomalies and cyclonic wind anomalies.

Fig. 3. Spatial patterns of (a) EOF1 and (b) EOF2 for summer precipitation anomalies over the North Asian region (30°–70°N, 70°–160°E) during 1979–2015 based on the GPCP data. The variance percentage is 15.3% for EOF1 and 12.5% for EOF2, respectively.
With this spatial distribution of the atmospheric circulation, it is not surprising to see the dipole pattern of summer precipitation indicated in Fig. 1c. It is also noted that the geopotential height shows from west to east consistent negative anomalies over northern NA and an overall north–south reverse-phase characteristic in NA. This might be the direct reason for the precipitation anomaly distribution changes into the zonal consistent phase structure in northern NA and the continuation of the north–south opposite phase pattern in eastern NA. When the EAP index is negative and the EU index is positive, the reverse-phase pattern with a “+ −” dipole distribution in the meridional direction is exhibited in the circulation field from low to high levels with an equivalent barotropic structure (Figs. 4d, 5d).

Additionally, we also used the 0.5 and 0.7 std deviations as thresholds for the EAP–EU configuration selection during the period of 1979–2015 (Table 1). It is obvious that the number of selected sample years gradually decreases with the increase of thresholds. The spatial distribution patterns of the geopotential height at 500 hPa for the four types of EAP–EU configurations correspond-
ing to the 0.5 (Fig. 6) and 0.7 std deviation (Fig. 7) thresholds are quite similar to that of Fig. 4. The geopotential height anomaly distribution shows a similar pattern to that of the 0.3 std deviation during the period of 1979–2015. Therefore, in order to meet the demand of the sample size and to properly present the summer precipitation and circulation characteristics of the EAP–EU configurations, this study mainly uses the 0.3 std deviation as the threshold for EAP–EU configuration selection.

As previously mentioned, the EU teleconnection is one of the five important teleconnection wave trains propagating from west to east over the EU continent. Normally, it presents high correlation centers located at (55°N, 20°E), (55°N, 75°E), and (55°N, 110°E). However, because of the influence of the meridional pattern over the EA and West Pacific, i.e., the EAP/PJ teleconnection, the spatial pattern of the EU teleconnection in the region of NA (overlapped with the northern lobe of the EAP teleconnection) may change in some years, although its upper reaches always keep the obvious teleconnection structure. This study has revealed the circulation patterns under four types of the EAP–EU configuration (Fig. 4). It is found that, when the EAP and EU teleconnections are in the same phase [i.e., Category I (II)], the geopotential height anomaly at 500 hPa maintains a zonal tripole structure from eastern Europe to the Sea of Japan. When the EAP and EU teleconnections are out of

![Fig. 6. As in Fig. 4, but for the 0.5 std deviation.](image)

![Fig. 7. As in Fig. 4 but for the 0.7 std deviation.](image)
phase [i.e., Category III (IV)], the teleconnection is not a well-structured one dictated by one or two very strong centers, as exemplified by Figs. 4c, d. The reason might be that the northern negative (positive) lobe of the EAP teleconnection overlaps with the central negative (positive) lobe and the eastern positive (negative) lobe of the EU teleconnection; this may strengthen the negative (positive) anomalies over the Baikal Lake region and weaken the positive (negative) anomalies over the Haití Okhotsk region, leading to consistent negative (positive) anomalies distributed from central China to Baikal Lake and Russian Far East.

Therefore, the EAP and EU teleconnections, NA summer precipitation, and mid–high-latitude circulations are closely linked to each other. For Category I (II) configuration, the summer precipitation and circulation in NA from northwest to southeast present a tripole wave pattern; whereas for Category III (IV) configuration, the precipitation and circulation anomaly fields show a dipole feature in the meridional direction. Meanwhile, the Category I (II) configuration represents the significant differences between the east and west parts of northern NA, whereas the Category III (IV) configuration implies consistent anomalies in northern NA. Furthermore, the south–north opposite pattern in eastern NA is maintained in both of the categories.

3.2 The synergistic effect of EAP and EU

The EAP teleconnection pattern mainly presents the distribution of the meridional tripole structure, reflecting the effect of low-latitude circulations on precipitation in EA (Huang, 2004; Zhou T. J. et al., 2009). The EU teleconnection shows the zonal wave pattern distribution, which reflects the effect of mid–high-latitude circulation on precipitation across the EU continent (Kosaka et al., 2009; Chen and Huang, 2012). In this section, we analyze the individual impact of the EAP and EU teleconnections on the summer precipitation in the midlatitudes of Eurasia, and propose the synergistic effect of the two teleconnections under different EAP–EU configurations.

Spatial distributions of the 500-hPa geopotential height and precipitation fields regressed onto the EAP and EU indices are shown in Figs. 8, 9, respectively. When the EAP index is positive, in the 500-hPa geopotential height field, the region from Baikal Lake to Okhotsk Sea is dominated by negative anomalies, and North China and Japan are controlled by positive anomalies (Fig. 8a), resulting in an anomalous increase in precipitation in the region from Baikal Lake to Okhotsk Sea, and an anomalous decrease in precipitation in the region from Northeast China to Japan (Fig. 9a). The EAP teleconnection mainly affects summer precipitation in eastern NA (30°–70°N, 120°–160°E) and creates north–south opposite meridional features (Huang J. P. et al., 1993; Huang R. H. et al., 2012). When the EU index is positive, the 500-hPa geopotential height in the midlatitude EU region is characterized by a “+ − +” wavelike pattern from northwest to southeast, and the anomaly centers are mainly located in Ural Mountain, Baikal Lake, and Okhotsk Sea areas (Fig. 8b), leading to more precipitation in Ural Mountain and Okhotsk Sea areas, as well as less precipitation over Baikal Lake (Fig. 8b). Thus, the EU type mainly affects the zonal mode of the summer precipitation in NA, especially in the northern region. Therefore, the EAP teleconnection mainly leads to a north–south dipole distribution in eastern NA, whereas the EU teleconnection mainly affects the zonal differences of summer precipitation in northern NA (Huang, 2004; Chen and Huang, 2012).

Figure 10 are schematic diagrams explaining the EAP–EU configuration in the 500-hPa geopotential height field. It can be seen from Fig. 10a that the EU index is positive with an abnormally high-pressure system located over the Ural Mountain and Okhotsk Sea areas, with an abnormally low system distributed over the Baikal Lake region. The EAP index is positive from Baikal Lake to Haití Okhotsk, which is controlled by a low-pressure system, whereas the area from Northeast China to Japan is dominated by a high-pressure system. The northern negative lobe of the EAP teleconnection overlaps with the central negative lobe and eastern positive lobe of the EU teleconnection, which may strengthen the negative anomalies over the Baikal Lake region and weaken the positive anomalies over the Haití Okhotsk region, leading to consistent negative anomalies distributed from central China to Baikal Lake and Russian Far East. Because the EU western positive lobe and the EAP southern positive lobe maintain their original phases, the 500-hPa geopotential height presents a zonal arc tripole pattern (Fig. 4a), and northern NA shows a west–east reverse-phase structure. In eastern NA, because of the dominant role played by the EAP teleconnection, the geopotential height maintains the dipole structure from north to south. According to the ω equation, such a spatial distribution of geopotential height anomalies will motivate the summer precipitation anomaly pattern as presented in Fig. 10a. According to the circulation anomalies, the precipitation over NA mainly presents the “+ − +” pattern from eastern Europe to the Sea of Japan. This precipitation structure is quite consistent with that in Fig. 2a. The same mechanism can explain the possible co-action of the configuration with both EAP and EU being in
negative phases (figure omitted).

When the EAP is positive and the EU is negative (Fig. 10b), the negative lobe of the EAP teleconnection over the area from Baikal Lake to Okhotsk Sea can weaken the positive anomalies of Eurasia over the Baikal Lake region, and form a negative anomaly band in northern NA. Additionally, the positive anomalies of Eurasia over the Baikal Lake region are also somewhat overlapped with the positive lobe of the EAP pattern, which may strengthen the positive anomalies in these regions. Accordingly, the spatial distribution of the geopotential height at the 500 hPa presents a “north-negative south-positive” pattern, causing more precipitation in northern NA but less in southern NA (Fig. 4c). Corresponding to the circulation anomalies, precipitation from eastern Europe to Russian Far East is mainly dominated by negative anomalies, whereas the area from North China to the Sea of Japan may have more precipitation. This precipitation structure is quite consistent with that in Fig. 2c. The same mechanism can be used to explain the possible co-impact of the configuration with negative EAP and positive EU (figure omitted).
3.3 Linear simulation of EAP–EU co-action

In order to verify the above analysis, based on the EAP index (\(I_{EAP}\)) and EU index (\(I_{EU}\)), a simplified two-element linear regression model was constructed to simulate the co-action of the EAP–EU configuration on the 500-hPa height and summer precipitation in NA.

\[ P = aI_{EAP} + bI_{EU} + e_P, \]  

\[ H = cI_{EAP} + dI_{EU} + e_H, \]

where \(P\) is the summer precipitation; \(H\) is the 500-hPa height; coefficients \(a, b, c,\) and \(d\) are determined by the binary regression method; and \(e\) is the residual term.

The EAP and EU indices are put into Eqs. (3) and (4), respectively, and the linear model can produce the regressed new precipitation and geopotential height fields. When only considering the case when the EAP and EU indices are both positive, and the case when the EAP is in positive phase but EU is in negative phase, the composite plots of the new 500-hPa geopotential height and precipitation fields are given in Figs. 11, 12, respectively. For Category I EAP–EU configuration (both positive), the 500-hPa geopotential height mainly presents the “+ − +” tripole distribution from northwest to southeast (Fig. 11a), with the anomalous positive centers distributed in Ural Mountain and Okhotsk Sea areas, and the negative center located in the eastern Baikal Lake area, which are consistent with the observed spatial pattern (Fig. 4a). This spatial consistency is also exhibited in the regressed (Fig. 12a) and observed (Fig. 2a) summer precipitation fields. For Category III (EAP positive and EU negative), the regressed 500-hPa height field in NA presents the “+ −” dipole structure in the meridional direction (Fig. 11b), with a positive anomaly belt distributed from the Ural Mountain area to Baikal Lake and Okhotsk Sea, and negative anomalies concentrated in North China to Japan and the maritime region, which is similar to the observed spatial anomaly distribution (Fig. 4c). The spatial distribution of regressed precipitation is also similar to that observed in Fig. 2c. Therefore, the EAP–EU co-action can be reproduced by the regression simulation. Since the other two configurations are respectively similar to the regressed two, relevant analysis is not repeated in this paper.

In order to further verify the role that the EAP and EU teleconnections play on influencing the geopotential height and precipitation in NA, the EAP and EU indices are doubled and put into the linear Eqs. (3) and (4), re-
spectively, to obtain new height and precipitation fields. Figures 11c, d and 12c, d show regressed 500-hPa geopotential height and precipitation on the two-time EAP index and one-time EU index. For Category I configuration with positive EAP and positive EU (Figs. 11c, 12c), anomalies of geopotential height and precipitation over the Baikal Lake area to Russian Far East are enhanced because of the enhancement of the EAP effect. The west–east reverse-phase characteristics over northern NA and the feature of the north–south opposite phases over eastern NA are further enhanced. For Category II configuration with positive EAP and negative EU (Figs. 11d, 12d), the north–south pattern in the meridional direction is obviously enhanced, especially over the eastern NA region. Therefore, it can be inferred that the EAP teleconnection plays a decisive role in strengthening the west–east differences over northern NA for Category I configuration, and in enhancing the north–south differences over eastern NA for Category II configuration.

Figures 11e, f and 12e, f show regressed 500-hPa geopotential height and precipitation on the one-time EAP index and two-time EU index, respectively. For Category I configuration with positive EAP and positive EU, the zonal wavelike structure in both 500-hPa height (Fig.

Fig. 11. Binary regressions of the summer 500-hPa geopotential height anomalies to EAP and EU indices for configurations of (a) EAP(+)/EU(+), (b) EAP(+)/EU(−), (c) 2EAP(+)/EU(+), (d) 2EAP(+)/EU(−), (e) EAP(+)/2EU(+), and (f) EAP(+)/2EU(−). Dotted areas indicate the 90% confidence level.

Fig. 12. As in Fig. 11 but for the summer precipitation anomalies.
11e) and precipitation (Fig. 12e) has been obviously enhanced, indicating that strong EU plays the dominant role in causing the zonal tripole pattern through an arc path across the EU continent. The enhanced EU effect also replaces the west–east reverse-phase distribution with three anomalous centers. This regressed three-center wave train associated with the EC teleconnection (Chen and Huang, 2012) is the result of propagation of the stationary Rossby wave activity from the source region over the North Atlantic. The only difference is that the eastern anomalous center of the EC teleconnection is shifted somewhat southward. For Category II configuration with positive EAP and negative EU, the 500-hPa height anomalies maintain the “north-negative south-positive” distribution. Compared with the distribution of original EAP and EU regressions, doubling the effect of Eurasia will increase the anomalous significance of meridional differences by enlarging the geopotential height (Fig. 11f) and precipitation (Fig. 12f) anomalies over the Ural Mountain area. Accordingly, the EU teleconnection adjusts the anomalous phase distribution in NA, especially influencing the anomaly distribution over northern NA.

Since the first two leading EOF modes somehow represent the summer precipitation patterns of the EAP–EU configuration (Fig. 3), the principal components (PC1 and PC2) may also partially indicate the main annual variability (Fig. 13). The $I_{\text{EAP}}$ and $I_{\text{EU}}$ regressed principal components (P1 and P2) according to Eq. (3) are presented in Fig. 13. The correlation coefficients between PC1 and P1 and between PC2 and P2 are respectively 0.51 and 0.68, both passing the 95% confidence level. That is to say, the EAP–EU joint effect can reproduce the annual variability of the EAP–EU configuration defined by the NA summer precipitation pattern.

$$P_1 = 0.414 \times I_{\text{EAP}} + 4.578 \times I_{\text{EU}} - 0.00025;$$  
$$P_2 = -4.741 \times I_{\text{EAP}} + 3.980 \times I_{\text{EU}} - 0.00021.$$  

Based on the above analysis, the mechanism of the synergistic impact of the EAP and EU teleconnections on climate anomalies in NA presumed in Section 3.2 is verified through the linear model simulation. The EAP northern lobe, when overlapped with the EU central and eastern lobes, can adjust the geopotential anomalies over the region from Baikal Lake to Russian Far East, causing the EAP–EU co-action on summer precipitation in NA. The EAP–EU co-action can motivate the zonal tripole wave-like pattern in the geopotential height and precipitation fields if the EAP and EU teleconnections have the same anomalous phase; it can also trigger the meridional dipole structure on the condition that the EAP and EU teleconnections are in opposite anomalous phases.

4. **Summary and conclusions**

Since both EAP and EU teleconnections have great impacts on the climate in EA and NA, this paper mainly analyzed the co-action of EAP–EU configuration on influencing summer climate anomalies in NA. A possible mechanism was proposed to explain the synergistic effect of the EAP–EU configuration by analyzing the individual teleconnection function. Meanwhile, a linear model simulation was also designed for the co-action mechanism. Main conclusions are summarized as follows.

1. The EAP and EU teleconnection patterns represent the meridional and zonal atmospheric circulation anomalies, respectively. The correlation coefficient between EAP and EU is 0.03, indicating that they are independent from each other and they have different effects on the summer precipitation in NA. The EAP teleconnection is negatively correlated with the precipitation over the extratropical region from middle East China to Japan, but positively associated with the precipitation in the Russian Far East and Okhotsk Sea regions, causing a north–south dipole distribution of precipitation anom-
ties in eastern NA. The EU teleconnection is negatively correlated with summer precipitation in the Ural Mountain and Okhotsk Sea regions, but positively associated with precipitation in the Baikal Lake region, which may lead to a tripole anomalous wavelike structure over northern NA.

(2) The EAP and EU teleconnections have synergistic effect on precipitation in NA. According to the index-based anomalous phases, the EAP and EU teleconnections can be divided into two categories of configurations: Category I (II) with EAP and EU teleconnections in the same anomalous phase, and Category III (IV) with two teleconnections in opposite anomalous phases. The Category I (II) configuration causes less (more) precipitation in the Ural Mountain area and Okhotsk Sea, and the region from Northeast China to Japan; and more (less) precipitation over Baikal Lake to Okhotsk Sea, leading to a “− + −” (“+ − +”) tripole wavelike structure in summer precipitation in NA. The Category I (II) configuration is associated with the west–east reversed anomalies of summer precipitation in northern NA and the north–south opposite anomalies in eastern NA. For the Category III (IV) configuration, summer precipitation has a consistent anomaly phase in northern NA, whereas precipitation in the EA region is still characterized by a meridional opposite phase structure, demonstrating an overall meridional dipole anomalous distribution of precipitation in NA.

(3) Composite analysis and linear model simulation have verified an EAP–EU co-action mechanism: with the EAP northern lobe overlapped with the EU central and eastern lobes, the geopotential height anomalies over Baikal Lake to Russian Far East are adjusted, which in turn cause the EAP–EU co-action on summer precipitation in NA. The EAP–EU co-action motivates the zonal tripole wavelike pattern in the geopotential height and precipitation fields if the EAP and EU teleconnections have the same anomalous phase; whereas it triggers the meridional dipole structure if the EAP and EU teleconnections are in opposite anomalous phases.

The EAP teleconnection pattern, originated from the low-latitude circulation system, mainly exerts influences on the summer climate in EA (Huang and Li, 1987; Nitta, 1987), while the EU teleconnection pattern is mainly associated with the atmospheric anomalies and EA climate over the middle- and high-latitude regions (Wallace and Gutzler, 1981; Wen et al., 2009). Although the EU teleconnection’s strongest impact presents mostly in winter, the EU pattern also has a significant impact on the summer climate in EA (Lee et al., 2005; Liu et al., 2014). Therefore, both EAP and EU teleconnections have important implications for summer precipitation in NA. This paper mainly derived that the different configurations of EAP and EU teleconnections have different impacts on the spatial pattern of summer precipitation anomaly in NA, or the principle modes of summer precipitation in NA. Additionally, the North Atlantic SST can stimulate the EU teleconnection wave train across the EU continent, and the North Pacific SST may affect the EAP teleconnection wave train through local sea–air interactions (Gong et al., 2018b). Accordingly, the North Atlantic SST and North Pacific SST are major external forcing factors affecting summer precipitation in NA. Therefore, it is necessary to conduct in-depth studies on the impact of external forcing on EAP and EU teleconnections, and especially to reveal the EAP–EU configurations relevant to the SST anomalies of the North Atlantic and North Pacific, as well as the associated dynamical mechanism. Meanwhile, quasi-resonant amplification (QRA) is a mechanism that affects extreme summer events in the Northern Hemisphere. We also need to pay attention to whether EAP and EU teleconnection patterns have a QRA phenomenon and impact on summer precipitation in EA (Kornhuber et al., 2017; Mann et al., 2018).

REFERENCES

Barnston, A. G., and R. E. Livezey, 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. Mon. Wea. Rev., 115, 1083–1126, doi: 10.1175/1520-0493(1987)115<1083:CSAPOL>2.0.CO;2.

Bjerknes, J., 1969: Atmospheric teleconnections from the equatorial pacific. Mon. Wea. Rev., 97, 163–172, doi: 10.1175/1520-0493(1969)097<0163:ATFTEP>2.3.CO;2.

Bueh, C., N. Shi, L. R. Ji, et al., 2008: Features of the EAP events on the medium-range evolution process and the mid- and high-latitude Rossby wave activities during the Meiyu period. Chinese Sci. Bull., 53, 610–623, doi: 10.1007/s11434-008-0005-2.

Chen, G. S., and G. H. Huang, 2012: Excitation mechanisms of the teleconnection patterns affecting the July precipitation in Northwest China. J. Climate, 25, 7834–7851, doi: 10.1175/jcli-d-11-00684.1.

Chen, Y., and P. M. Zhai, 2015: Synoptic-scale precursors of the East Asia/Pacific teleconnection pattern responsible for persistent extreme precipitation in the Yangtze River Valley. Quart. J. Roy. Meteor. Soc., 141, 1389–1403, doi: 10.1002/qj.2448.

Chen, Y., P. M. Zhai, Z. Liao, et al., 2019: Persistent precipitation extremes in the Yangtze River Valley prolonged by optimum configuration among atmospheric teleconnections. Quart. J. Roy. Meteor. Soc., 145, 2603–2626, doi: 10.1002/qj.3581.

Dogar, M. M., F. Kucharski, and S. Azharuddin, 2017: Study of the global and regional climatic impacts of ENSO magnitude using SPEEDY AGCM. J. Earth Syst. Sci., 126, 30, doi:
Fan, K., and H. J. Wang, 2004: Antarctic oscillation and the dust weather frequency in North China. Geophys. Res. Lett., 31, L10201, doi: 10.1029/2004GL019465.

Gong, Z. Q., M. M. A. Dogar, S. B. Qiao, et al., 2017: Limitations of BCC_CSM’s ability to predict summer precipitation over East Asia and the Northwestern Pacific. Atmos. Res., 193, 184–191, doi: 10.1016/j.atmosres.2017.04.016.

Gong, Z. Q., M. M. Dogar, S. B. Qiao, et al., 2018a: Assessment and correction of BCC_CSM’s performance in capturing leading modes of summer precipitation over North Asia. Int. J. Climatol., 38, 2201–2214, doi: 10.1002/joc.5327.

Gong, Z. Q., G. L. Feng, M. M. Dogar, et al., 2018b: The possible physical mechanism for the EAP-SR co-action. Climate Dyn., 51, 1499–1516, doi: 10.1007/s00382-017-3967-4.

Grotjahn, R., R. Black, R. Leung, et al., 2016: North American extreme temperature events and related large scale meteorological patterns: A review of statistical methods, dynamics, modeling, and trends. Climate Dyn., 46, 1151–1184, doi: 10.1007/s00382-015-2638-6.

Hingmire, D., R. K. Vellore, R. Krishnan, et al., 2019: Widespread fog over the Indo-Gangetic Plains and possible links to boreal winter teleconnections. Climate Dyn., 52, 5477–5506, doi: 10.1007/s00382-018-4458-y.

Hoskins, B. J., and D. J. Karoly, 1981: The steady linear response of a spherical atmosphere to thermal and orographic forcing. J. Atmos. Sci., 38, 1179–1196, doi: 10.1175/1520-0469(1981)038<1179:TSLLRO>2.0.CO;2.

Huang, G., 2004: An index measuring the interannual variation of the East Asian summer monsoon—The EAP index. Adv. Atmos. Sci., 21, 41–52, doi: 10.1007/bf02951679.

Huang, J. P., Y. H. Yi, S. W. Wang, et al., 1993: An analogue-dynamical long-range numerical weather prediction system incorporating historical evolutions. Quart. J. Roy. Meteor. Soc., 119, 547–565, doi: 10.1002/qj.49771951111.

Huang, R. H., and W. J. Li, 1987: Influence of the heat source anomaly over the tropical western Pacific on the subtropical high over East Asia. Proc. Int. Conf. on the General Circulation of East Asia, Chengdu, China, Institute of Atmospheric Physics, Chinese Academy of Sciences, 40–51.

Huang, R. H., and F. Y. Sun, 1992: Impacts of the tropical western Pacific on the East Asian summer monsoon. J. Meteor. Soc. Japan, 70, 243–256, doi: 10.2151/jmsj1965.70.1B_243.

Huang, R. H., J. L. Chen, and G. Huang, 2007: Characteristics and variations of the East Asian monsoon system and its impacts on climate disasters in China. Adv. Atmos. Sci., 24, 993–1023, doi: 10.1007/s00376-007-0993-x.

Huang, R. H., J. L. Chen, L. Wang, et al., 2012: Characteristics, processes, and causes of the spatio-temporal variabilities of the East Asian monsoon system. Adv. Atmos. Sci., 29, 910–942, doi: 10.1007/s00376-013-0001-6.

Kornhuber, K., V. Petoukhov, S. Petri, et al., 2017: Evidence for wave resonance as a key mechanism for generating high-amplitude quasi-stationary waves in boreal summer. Climate Dyn., 49, 1961–1979, doi: 10.1007/s00382-016-3399-6.

Kosaka, Y., H. Nakamura, M. Watanabe, et al., 2009: Analysis on the dynamics of a wave-like teleconnection pattern along the summertime Asian jet based on a reanalysis dataset and climate model simulations. J. Meteor. Soc. Japan, 87, 561–580, doi: 10.2151/jmsj.87.561.

Lee, E. J., J. G. Jhun, and C. K. Park, 2005: Remote connection of the Northeast Asian summer rainfall variation revealed by a newly defined monsoon index. J. Climate, 18, 4381–4393, doi: 10.1175/JCLI3545.1.

Li, J., R. C. Yu, and T. J. Zhou, 2008: Teleconnection between NAO and climate downstream of the Tibetan Plateau. J. Climate, 21, 4680–4690, doi: 10.1175/2008JCLI2053.1.

Li, J. Y., and J. Y. Mao, 2018: The impact of interactions between tropical and midlatitude intraseasonal oscillations around the Tibetan Plateau on the 1998 Yangtze floods. Quart. J. Roy. Meteor. Soc., 144, 1123–1139, doi: 10.1002/qj.3279.

Li, J. Y., and J. Y. Mao, 2019: Coordinated influences of the tropical and extratropical intraseasonal oscillations on the 10–30-day variability of the summer rainfall over southeastern China. Climate Dyn., 53, 137–153, doi: 10.1007/s00382-018-4574-8.

Li, L., P. M. Zhai, Y. Chen, et al., 2016: Low-frequency oscillations of the East Asia–Pacific teleconnection pattern and their impacts on persistent heavy precipitation in the Yangtze–Huai River Valley. J. Meteor. Res., 30, 459–471, doi: 10.1007/s13535-016-0604-z.

Lin, Z. D., and R. Y. Lu, 2016: Impact of summer rainfall over southern–central Europe on circumpolar global teleconnection. Atmos. Sci. Lett., 17, 258–262, doi: 10.1002/asl.652.

Liu, Y. Y., L. Wang, W. Zhou, et al., 2014: Three Eurasian teleconnection patterns: Spatial structures, temporal variability, and associated winter climate anomalies. Climate Dyn., 42, 2817–2839, doi: 10.1007/s00382-014-2163-z.

Lu, R. Y., 2004: Associations among the components of the East Asian summer monsoon system in the meridional direction. J. Meteor. Soc. Japan, 82, 155–165, doi: 10.2151/jmsj.82.155.

Lu, R. Y., Y. Li, and B. W. Dong, 2006: External and internal summer atmospheric variability in the western North Pacific and East Asia. J. Meteor. Soc. Japan, 84, 447–462, doi: 10.2151/jmsj.84.447.

Mann, M. E., S. Rahmstorf, K. Kornhuber, et al., 2018: Projected changes in persistent extreme summer weather events: The role of quasi-resonant amplification. Sci. Adv., 4, eaat3272, doi: 10.1126/sciadv.aat3272.

Nitta, T., 1987: Convective activities in the tropical western Pacific and their impact on the Northern Hemisphere summer circulation. J. Meteor. Soc. Japan, 65, 373–390, doi: 10.2151/jmsj1965.65.3_373.

Nitta, T., and Z. Z. Hu, 1996: Summer climate variability in China and its association with 500 hPa height and tropical convection. J. Meteor. Soc. Japan, 74, 425–445, doi: 10.2151/jmsj1965.74.4_425.

Ogasawara, T., and R. Kawamura, 2007: Combined effects of teleconnection patterns on anomalous summer weather in Japan. J. Meteor. Soc. Japan, 85, 11–24, doi: 10.2151/jmsj.85.11.

Ogasawara, T., and R. Kawamura, 2008: Effects of combined teleconnection patterns on the East Asian summer monsoon circulation: Remote forcing from low- and high-latitude regions. J. Meteor. Soc. Japan, 86, 491–504, doi: 10.2151/jmsj.86.491.

Srinivas, G., J. S. Chowdary, Y. Kosaka, et al., 2018: Influence of the Pacific–Japan pattern on Indian summer monsoon rainfall. J. Climate, 31, 3943–3958, doi: 10.1175/JCLI-D-17-0408.1.

Tachibana, Y., T. Nakamura, and N. Tazou, 2007: Interannual variation in snow-accumulation events in Tokyo and its relationship to the Eurasian pattern. SOLA, 3, 129–132, doi: 10.2151/sola.2007-033.

Takaya, K., and H. Nakamura, 2013: Interannual variability of the
East Asian winter monsoon and related modulations of the planetary waves. *J. Climate*, 26, 9445–9461, doi: 10.1175/JCLI-D-12-00842.1.

Ueda, H., T. Yasunari, and R. Kawamura, 1995: Abrupt seasonal change of large-scale convective activity over the western Pacific in the northern summer. *J. Meteor. Soc. Japan*, 73, 795–809, doi: 10.2151/jmsj1965.73.4_795.

Wakabayashi, S., and R. Kawamura, 2004: Extraction of major teleconnection patterns possibly associated with the anomalous summer climate in Japan. *J. Meteor. Soc. Japan*, 82, 1577–1588, doi: 10.2151/jmsj.82.1577.

Wallace, J. M., and D. S. Gutzler, 1981: Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev.*, 109, 784–812, doi: 10.1175/1520-0493(1981)109<0784:TITGHF<2.0.CO;2.

Wang, H., B. Wang, F. Huang, et al., 2012: Interdecadal change of the boreal summer circumglobal teleconnection (1958–2010). *Geophys. Res. Lett.*, 39, L12704, doi: 10.1029/2012GL052371.

Wang, L., and W. Chen, 2014: An intensity index for the East Asian winter monsoon. *J. Climate*, 27, 2361–2374, doi: 10.1175/JCLI-D-13-00086.1.

Wang, L. J., C. Wang, and D. Guo, 2018: Evolution mechanism of synoptic-scale EAP teleconnection pattern and its relationship to summer precipitation in China. *Atmos. Res.*, 214, 150–162, doi: 10.1016/j.atmosres.2018.07.023.

Wang, N., and Y. C. Zhang, 2015: Connections between the Eurasian teleconnection and concurrent variation of upper-level jets over East Asia. *Adv. Atmos. Sci.*, 32, 336–348, doi: 10.1007/s00376-014-4088-1.

Wen, M., S. Yang, A. Kumar, et al., 2009: An analysis of the large-scale climate anomalies associated with the snowstorms affecting China in January 2008. *Mon. Wea. Rev.*, 137, 1111–1131, doi: 10.1175/2008MWR2638.1.

Yang, R. W., Y. Tao, and J. Cao, 2010: A mechanism for the interannual variation of the early summer East Asia–Pacific teleconnection wave train. *Acta Meteor. Sinica*, 24, 452–458.

Zhou, T. J., B. Wu, and B. Wang, 2009: How well do atmospheric general circulation models capture the leading modes of the interannual variability of the Asian–Australian monsoon? *J. Climate*, 22, 1159–1173, doi: 10.1175/2008jcli2245.1.

Zhou, W., J. C. L. Chan, W. Chen, et al., 2009: Synoptic-scale controls of persistent low temperature and icy weather over southern China in January 2008. *Mon. Wea. Rev.*, 137, 3978–3991, doi: 10.1175/2009MWR2952.1.