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Article

Relationship between the Silk Road and Circumglobal Teleconnection Patterns on the Interannual and Interdecadal Timescales

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Abstract: The Silk Road pattern (SRP) and Circumglobal teleconnection pattern (CGT) are two well-known teleconnection patterns along the Eurasian westerly jet during boreal summer, which are often regarded as one teleconnection pattern. In view of the distinct features of the SRP/CGT on the interannual (IA) and interdecadal (ID) timescales, the present study investigates the linkages and differences between the SRP and CGT on the two timescales. On the IA timescale, the SRP and CGT feature a similar circumglobal wave train structure with strong and significant centers over Eurasia, but show clear independences. Specifically, the SRP and CGT illustrates largely the mid-/high-latitude-related and tropics-related parts of the Northern Hemisphere upper-tropospheric circulation variations, respectively. Also, the CGT shows a stronger connection to the Indian summer monsoon (ISM) heating and El Niño–Southern Oscillation than the SRP, which makes the CGT more like a tropical-forcing-driven atmospheric mode but the SRP more like an internal atmospheric mode. The linkages and differences between them are associated with their asymmetry relationship during their positive and negative phases, which are attributed mainly to the asymmetry impact of the ISM heating/cooling on the Eurasian circulations. On the ID timescale, the SRP and CGT are characterized by a coherent two-wave train structure over Eurasia, and feature more like the same teleconnection pattern, which are associated with the Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation. The present findings on the linkages and differences between the SRP and CGT are helpful to understand the variability and prediction of the SRP and CGT.

Keywords: Silk Road pattern; circumglobal teleconnection pattern; linkages and differences; interannual and interdecadal timescales

1. Introduction

During the last two decades, two well-known teleconnection patterns have been identified along the Eurasian westerly jet during boreal summer, which are respectively the Silk Road pattern (SRP; Lu et al. 2002; Enomoto et al. 2003) and the circumglobal teleconnection pattern (CGT; Ding and Wang 2005). The SRP is the leading mode of the upper-tropospheric meridional wind anomalies over Eurasia during boreal summer (Yasui and Watanabe 2010; Kosaka and Nakamura 2010). The CGT represents the second leading mode of the upper tropospheric circulation in the Northern Hemisphere (NH), which features a recurrent circumglobal pattern over the NH mid-latitudes (Ding and Wang 2005). Despite of their distinct definitions, the SRP and CGT depict an identical structure, in particular over Eurasia, and are therefore often deemed to be the same teleconnection pattern and have been widely investigated due to their great impacts on the NH mid-latitude summer climate variations on both the interannual (IA) and interdecadal (ID) timescales (Sato and Takahashi 2006; Huang et al. 2011, 2013; Kosaka et al. 2011; Gong et al. 2018; Hong et al. 2017; Wang et al. 2017; Liu and Huang 2019).

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On the IA timescale, the SRP and CGT (referred to as IA-SRP and IA-CGT) are considered as a stationary Rossby wave train along the Eurasian westerly jet that can be self-maintained by extracting kinetic and available potential energy from the basic flow (Lu et al. 2002; Enomoto et al. 2003; Enomoto 2004; Sato and Takahashi 2006; Kosaka et al. 2009; Chen and Huang 2012; Chen et al. 2013). They can also be modulated or triggered by the atmospheric external forcings, such as the tropical Indian summer monsoon (ISM) heating (Lu et al. 2002; Wu 2002; Ding and Wang 2005; Ding et al. 2011), mid-latitude heating over southern Europe and the eastern Mediterranean (Sato and Takahashi 2006; Lin and Lu 2016; Lin et al. 2017), the El Niño-Southern Oscillation (ENSO; Ding and Wang 2005; Chen and Huang 2012), and the summer North Atlantic oscillation (SNAO; Liu et al. 2019). Furthermore, owing to the changes in the variability of these external forcings, the IA-SRP/IA-CGT structure has experienced remarkable ID changes. For example, the IA-SRP/IA-CGT is intensified over its Europe and West Asia portion around the late-1970s, which is attributed to the weakened impact of the ISM precipitation (Wu and Wang 2002; Wang et al. 2012; Lin et al. 2017) and enhanced impacts of the SNAO (Liu et al. 2019) since the late-1970s.

On the ID timescale, the SRP (referred to as ID-SRP) shows a different structure from its IA counterpart, characterized by a wave train pattern with a larger meridional scale over Eurasia (Wang et al. 2017; Hong et al. 2018). It also experienced two ID changes (or phase transitions), one around the mid/late-1970s and the other in the late-1990s (Wang et al. 2017; Stephan et al. 2019), which may be associated with the phase shifts of the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO). By analyzing the CGT spatial-temporal structure without removing its ID component, Wang et al. (2013) pointed out that the CGT reveals evident ID variations with clear weakening around the late-1970s and enhancement after the late-1990s (see their Figure 1b), despite the ID-CGT explaining a lower percentage of the NH upper tropospheric circulation variation than the IA-CGT. In addition, Wu et al. (2016) identified an ID-CGT pattern along the Eurasian polar jet that resembles the British-Baikal Corridor (BCC) pattern (Xu et al. 2019) but is different from the conventional CGT along the Eurasian westerly jet.

Due to their high spatial-temporal similarity (Zhou et al. 2019), most of the previous studies have treated the SRP and CGT as the same teleconnection pattern or regarded the SRP as the Eurasian portion of the CGT particularly on the IA timescale, and used the names of SRP and CGT alternatively. Relatively few works have paid attention to the linkages and differences between the two teleconnection patterns. Recently, Zhou et al. (2019) investigated the linkages and differences between the SRP and CGT by using the unfiltered datasets, and indicated that the SRP is an internally inherent mode in the upper troposphere over Eurasia and the CGT is a section of the SRP, which is different from previous understanding that the SRP is a regional manifestation of the CGT pattern (Ding and Wang 2005). Given the distinct variations of the two teleconnection patterns on the IA and ID timescales, it is hypothesized that the SRP-CGT relationship may vary on different timescales. Therefore, following Zhou et al. (2019), the present study conducts a further investigation on the linkages and differences between the SRP and CGT on both the IA and ID timescales, as well as their associations with the NH summer climate, tropical/extropical heating (precipitation) and global-ocean sea surface temperature (SST) anomalies, aiming to provide a comprehensive understanding of the SRP–CGT relationship.

The rest of this paper is organized as follows. Section 2 describes the data and methods used in this study. Sections 3 revisits the spatial-temporal features of the SRP and CGT on the IA and ID timescales. In section 4, we investigate the linkages and differences between the two teleconnection patterns on the IA and ID timescales, separately, including the independences of the two teleconnection patterns as well as their links to the NH summer climate, tropical and extra-tropical heating and global ocean SST anomalies. Section 5 gives the conclusions and a discussion.

1. Data and method

The monthly observational and reanalysis datasets used in this study include: (1) the atmospheric circulation and surface air temperature from the National Centers for Environmental Prediction and Atmospheric Research (Kalnay et al. 1996); (2) the precipitation from the National

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Oceanic and Atmospheric Administration's precipitation reconstruction (PREC) dataset (Chen et al. 2002); and (3) global SST from the Hadley Centre (Rayner 2003). Also used are the PDO index and AMO index, which were downloaded respectively from https://www.esrl.noaa.gov/psd/data/correlation/pdo.data and https://www.esrl.noaa.gov/psd/data/correlation/amon.us.data. All datasets covered the boreal summer (June-July-August, JJA) during 1961-2018 uncless otherwise stated.

Regarding the SRP, there are about five different definitions based on different domains that are listed in Table 1. Different from the other three definitions, the definitions by Lu et al. (2002) and Sato and Takahashi (2006) focus on the SRP (200-hPa meridional wind; *V200*) variations mainly over the East Asia. In view of the SRP active centers spreading zonally over Eurasia, we select the definition of Yasui and Watanabe (2010) that defined the SRP as the first empirical orthogonal function (EOF) mode of the summer mean *V200* over the region (20°N–60°N; 0°–150°E; Figure 1a) that covers all active centers of the SRP over Eurasia. The SRP index (SRPI, Figure 1c) is accordingly defined as the normalized first principal component (PC). The SRP accounts for about 28.3% of the total variance of the *V200* anomalies, which is highly consistent with the SRP defined by Kosaka et al. (2009) and Chen and Huang (2012), which are based on slightly different domains (Table 1). The results are insensitive to these slight changes.

As mentioned above, the CGT is firstly detected from the second EOF of the NH geopotential height at the 200-hPa level (*Z200*) on the IA timescale (Ding and Wang, 2005), while the second EOF of the unfiltered NH *Z200* (Figure S1) and the first coupled mode between the unfiltered NH *Z200* and tropical precipitation also resemble the CGT pattern (Figure 2 in Wang et al. 2013). Given this, we follow Ding and Wang (2005) and define the CGT index (CGTI, Figure 1d) as the *Z200* anomalies averaged over the area (35°N–40°N; 60°–70°E), and define the corresponding *Z200* anomaly pattern over the NH as the CGT pattern (Figure 1b). The CGT accounts for about 7.3% of the total *Z200* variance over the NH and 17.4% over the region (20°N–60°N; 0°–150°E). Also, the correlation coefficients between the CGTI and the PC of the second EOF of the NH *Z200* anomalies (to the north of 20°N) on the total, IA and ID timescales are 0.38, 0.48 and 0.37, respectively, which are significant at 91%, 95% and 90% confidence level, respectively.

In the present study, we find that the linear trend has a substantial effect on the ID variations of the SRP and CGT. Hence, to obtain their IA and ID variations clearly, the linear trend is firstly removed from the original data and indices. Then, the IA components are extracted from the detrended data/indices using a 9-yr Lanczos high-pass filter (Duchon 1979), and the residual of the detrended data/indices is defined as the ID components. For the sake of convenience, the SRP and CGT on the IA and ID timescales are referred to as IA-SRP, IA-CGT, ID-SRP and ID-CGT, respectively. In addition, the correlation/regression and partial correlation/regression methods are used in the following analyses. The confidence level of correlation/regression is estimated by the two-tailed *Student's t-test*. The effective degree of freedom is evaluated following Metz (1991).

1. Spatial-temporal features of the SRP and CGT on the IA and ID timescales

In this section, we contrast the spatial-temporal features of the SRP and CGT on the IA and ID timescales. Given their different definitions, both the *V200* and *Z200* anomalies related to the two teleconnection patterns are contrasted, aiming to achieve an intuitive and objective view of the SRP-CGT relationship. To begin our analysis, the spatial-temporal features of the total SRP and CGT (not detrended) are provided for comparison.

Figures 1a-b display the *V200*/*Z200* anomalies regressed onto the total SRPI and CGTI (Figures 1c-d). Corresponding to the total SRP and CGT, both the *V200* and *Z200* anomalies feature clear circumglobal wave train patterns within the Eurasian westerly jet, having strong and signficant active centers over Eurasia. Specifically, in terms of the *V200* anomalies, both the total SRP and CGT have five active centers over Eurasia, including two positive ones over the eastern Europe and eastern China and three negative ones over the western Europe, central Asia and Korea-Japan, showing high similarity with a spatial correlation coefficient of 0.87 within the domain (15°N–75°N; 0°–360°E; hereafter the spatial correlation is calculated over this domain unless specified otherwise). One

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exception is that the total CGT-related anomalies are slightly weaker and the anomalies in the East Asian portion move slightly more eastward compared to the total SRP-related anomalies. In terms of the *Z200* anomalies, both the total SRP and CGT have four strong active centers over Eurasia, including two positive ones over the central Asia and eastern Asia and two negative ones over the western Europe and North China, except that the negative center related to the total CGT over North China spreads across a large domain and extends to the eastern Siberia. The spatial correlation coefficient is 0.65 in terms of *Z200* anomalies, which increases to 0.72 over the Eurasian portion (15°N–75°N; 0–160°E). This indicates that the total SRP and CGT reveal a weaker coherence in the *Z200* anomalies than in the *V200* anomalies. This difference is due to an opposite structure of the *Z200* anomalies over the North Pacific, North America and North Atlantic. By contrast, the total SRP has stronger negative centers but weaker positive centers compared to the total CGT.

As for their temporal features, the total SRPI and CGTI reveal significant IA and ID variations (Figures 1c-f). On the IA timescale, the SRP and CGT feature prominent periodocity of the 2-4 years before the late-1970s and the 4-8 years during the 1980s to the mid-1990s (Figures 1e-f), consisent with Wang et al. (2012) and Liu et al. (2019). On the ID timescale, the SRP and CGT show coherent phase transitions around the mid-1970s, late-1980s, and early-2010s (Figures 1c-d). The IA-SRPI (IA-CGTI) accounts for about 57.1% (69.8%) of total variance of the total SRPI (CGTI), which is much larger than the ID-SRPI (ID-CGTI), which explains about 13.4% (15.9%) of the total variance of the total SRPI (CGTI) (Table 2). This indicates that the SRP and CGT depict largely the IA variability of the NH upper-tropospheric circulation. In addition, the SRPI and CGTI are closely interrelated, with correlation coefficients of 0.53, 0.72 and 0.88 on the total, IA and ID timescales, respectively. All the above correlation coefficients are beyond the 95% confidence level (Table 3). Also, the variability of the SRP and CGT are highly coherent on the IA timescale (more so than on the ID timescale) particularly prior to the early-1990s (Figures 1e-f).

Here, it should be noted at this point that the phase transition timings and the percentage variances of the detrended ID-SRPI and ID-CGTI are different from in previous studies (Wang et al. 2017; Hong et al. 2018). These discrepancies are due to the effects of the linear trends of the data/indices which are removed in the present study. The removal of linear trends greatly influences the ID variations of the two teleconnection patterns, which however, was not excluded in many previous studies. To prove it, the IA and ID indices of the two teleconnection patterns are re-extracted from the total indices without removing their linear trends, and the same analyses are performed on these indices. When the linear trend is retained, their correlations and percentage variances of IA-SRPI and IA-CGTI remain nearly the same, but those of ID-SRPI and ID-CGTI alter greatly (Tables 2-3). The non-detrended ID-SRPI shows phase transitions around the mid-1970s and late-1990s rather than the late-1980s, with clear differences from the detrended ID-SRPI since the late-1990s (Figure 1c). These results are consistent with Wang et al. (2017). The non-detrended ID-CGTI exhibits phase transitions around the mid-1970s, the late-1980s, the late-1990s and the mid-2000s and has intensified amplitude during the periods prior to the late-1970s and after the early-2010s and weakened amplitude during the periods from the late-1980s to the late-2000s (Figure 1d; dotted blue line). The percentage variances of the non-detrended ID-SRPI and ID-CGTI increase to 37.3% and 23.8%, respectively. Furthermore, the correlation coefficient between the ID-SRPI and ID-CGTI decreases to about 0.22, far below the 90% confidence level, which is attributed to the opposite linear trend of the total SRP and CGT indices. These contrasting results confirm the strong impact of the linear trend on the ID-SRP and ID-CGT, which is also seen in the following analysis, implying the need to remove the linear trend when studying the ID variations of the two teleconnection patterns. Therefore, in the following analyses, we investigate the SRP–CGT relationship on the IA and ID timescales based on the detrended data and indices.

Figure 2a displays the *V200*/*Z200* anomalies associated with the IA-SRP and IA-CGT. Both show a similar circumglobal wave train over the NH mid-latitudes with significant and strong centers over Eurasia. Compared to the total SRP and CGT, the IA-SRP and IA-CGT are more coherent with spatial correlation coefficients between them of 0.88 and 0.80 in terms of the *V200* and *Z200* anomalies, respectively. Also, the associated wave train structures are much clearer, particularly in the *Z200*

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anomalies. Specifically, the *V200* anomalies relevant to the two IA teleconnection patterns bear a similar structure to their total counterparts but with larger amplitude (Figure 2a). While, the *Z200* anomalies associated with the IA-SRP differ largely from the total SRP, displaying a clearer wave train structure with negative centers over the western Europe and northwestern China-Mongolia and positive centers over the central Asia and eastern Asia (Figure 2b). As for the IA-CGT, both the *V200* and *Z200* anomalies are stronger and have clearer negative centers than those of the total CGT. Furthermore, the *Z200* anomalies associated with the IA-SRP and IA-CGT are also accompained by another wave train over the high latitudes of Eurasia, albeit the *Z200* anomalies are statistically insignificant. In contrast to the IA-CGT, the IA-SRP has stronger and more significant negative centers in terms of either the *V200* or *Z200* anomalies over Eurasia. This situation is reversed for their positive centers. This suggests that the IA-SRP has a stronger connection to the circulation anomalies over Europe than the IA-CGT.

On the ID timescale, the SRP and CGT bear a high spatial similarity, with spatial correlation coefficients of 0.97 in both the *V200* and *Z200* anomalies, which, however reveal notable differences from their total and IA counterparts. As shown in Figure 2c, the associated *V200* anomalies display a two-wave train structure over Eurasia: one mid-/low-latitude wave train along the southern part of the westerly jet and another mid-/high-latitude one along the polar jet. The mid-/low-latitude wave train consists of four strong centers over the Caspian Sea, central Asia, central China and Korea-Japan. These centers are situated southward and westward compared to their total and IA counterparts, with a narrower zonal scale and weaker amplitude over the Northwest and central China. The mid-/high-latitude one also has four centers along 60°N, including two strong negative centers over the western Europe and northern Russia and two positive ones over the eastern Europe and eastern Siberia. The associated *Z200* anomalies also feature a two-wave train structure over Eurasia with a weak wave train and a prominent one situated to the south and north of about 50°N over Eurasia, respectively (Figure 2d). The prominent one has four strong centers over the North Atlantic, western Europe, North Russia and eastern Siberia, respectively. The weak one consists of two positive centers over the West and South China and a weak negative center over Japan. Compared with their total and IA counterparts, the *V200*/*Z200* anomalies are weak, insignificant, and not well organized over the North Pacific and North America, and the negative centers are stronger and situated northward and westward over the western Europe. In addition, it is worth noting that the high-latitude wave train patterns of the *V200*/*Z200* anomalies resemble the BCC pattern (Xu et al. 2019). Here, we calculate the correlation coefficients of the BCC index (PC of the first EOF of the *V250* over 50°N-80°N; 20°W-150°E; Xu et al. 2019) with the SRPI and CGTI on the ID timescale, which have value of 0.52 (significant at the 92% confidence level) and 0.39 (significant at the 76% confidence level), respectively. This indicates some connections between the ID-SRP and ID BCC.

The SRP and CGT structures mentioned above are consistent with previous findings on the IA timescale but show different features on the ID timescale noted by Wang et al. (2017) and Hong et al. (2018). The differences are due to the effect of linear trends that have been removed in this study. This is supported by the SRP and CGT structures on the IA and ID timescales without removing the linear trend from the data and indices, which are shown in Figure S2. It can be seen that the non-detrended SRP and CGT are similar to the detrended ones on the IA timescale but differ considerably on the ID timescale. In particular, the non-dtrended ID-SRP and ID-CGT show weaker spatial coherence than the detrended ones. These results further confirm that the linear trend affects greatly the ID variations of the SRP and CGT.

1. Relationships between the SRP and CGT on the IA and ID timescales

Although the SRP and CGT show highly spatial-temporal similarity on both the IA and ID timescales, remarkable differences are also noticeable in their spatial structures. To uncover the differences and linkages between the SRP and CGT, we employ the partial regression method to investigate the independences of the two teleconnection patterns on the IA and ID timescales, respectively. Meanwhile, the links of the two teleconnection patterns to the NH summer precipitation and surface air temperature (*Ts*) anomalies, as well as their links to the tropical/extra-tropical heating

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(precipitation) and global-ocean SST anomalies are examined in this section, aming to provide a better understanding of the SRP–CGT relationships. For simplicity, the independent parts of the two teleconnection patterns are termed as the isolated SRP and isolated CGT, respectively.

4.1. Relationship between the SRP and CGT on the IA timescale

a. Independent parts of the IA-SRP and IA-CGT

Figure 3 displays the *V200* and *Z200* anomalies related to the independent parts of the IA-SRP and IA-CGT. In terms of the *V200* anomalies, the isolated IA-SRP reproduces the major wave train structure of the IA-SRP with a spatial correlation coefficient of 0.82 between them (Figure 3a). In contrast to the IA-SRP, the isolated IA-SRP is stronger and has a larger meridional scale, with clear enhancement over the high-latitude Eurasia except that the isolated IA-SRP weakens evidently over the eastern China and Korea-Japan. In addition, the isolated IA-SRP centers move slightly northward and westward over the region from the North Atlantic to central Asia. As for the isolated IA-CGT (Figure 3b), it shows considerable alternations and has a spatial correlation coefficient of 0.58 with the IA-CGT. Specifically, the isolated IA-CGT is characterized by a notable two-wave train structure over Eurasia. The first wave train is located to the north of about 45°N along the polar jet with positive centers over the western Europe and central Russia and negative centers over the eastern Europe and eastern Siberia, showing oppoiste structures to those of the IA-CGT and isolated IA-SRP. The second wave train is located to the south of about 45°N with two strong positive centers over the southern Europe and eastern China and two strong negative centers over the Northwest China and Japan. It is also apparent that the strong positive center of the IA-CGT over the Caspian Sea disappears in the isolated IA-CGT, and the isolated IA-CGT shows an opposite structure to the isolated IA-SRP over the North Atlantic, North Pacific and North America. Despite of these differences, the *V200* anomalies associated with the isolated IA-CGT match well with those related to the IA-CGT over the eastern Asia though the *V200* anomalies are slightly weaker and move slightly southward and eastward.

In terms of the *Z200* anomalies, the isolated IA-SRP and isolated IA-CGT feature a nearly zonal uniform pattern with almost opposite anomalies over the NH extra-tropics (Figures 3c-d), which resembles the extra-tropical circulation responses to ENSO (Trenberth et al. 1998; Seager et al. 2003; and many others). Compared to the IA-SRP (IA-CGT), the isolated IA-SRP (IA-CGT) has much weaker positive (negative) centers and stronger negative (positive) centers that almost overlap with those related to the IA-SRP (IA-CGT), but the strong positive (negative) centers of the IA-SRP (IA-CGT) disappear in the isolated IA-SRP (IA-CGT). The *Z200* anomalies related to the isolated IA-CGT resemble well the second EOF mode of the *Z200* anomalies in the NH, which is defined as the CGT pattern (Figure 4b in Ding and Wang 2005) but also accompained by another significant wave train over the high-latitude Eurasia. The spatial correlation coefficient between the IA-CGT and its independent part is 0.74, which is slightly larger than that for the IA-SRP with a value of 0.65.

The above results indicate that the isolated IA-SRP and isolated IA-CGT retain the major structure of the IA-SRP/IA-CGT over the northern and southern parts of the NH (to the north and south of about 45°N), respectively. This is further supported by the spatial correlations between the IA-SRP/IA-CGT and their independent parts within the following two domains of (15°N–45°N; 0°–360°E) and (45°N–75°N; 0°–360°E), particularly in *Z200* anomalies (Table 4). These features are different from the findings of Zhou et al. (2019) who overlooked the differences between the two teleconnection patterns on the IA and ID timescales. Along with the results in section 3, it is apparent that the coherent wave train structures of the IA-SRP and IA-CGT feature a combined result of the isolated IA-SRP and isolated IA-CGT in either the *V200* or *Z200* anomalies. By contrast, the isolated IA-SRP plays a leading role in the IA-SRP and IA-CGT variations over the NH mid-/high-latitudes (to the north of 45°N), while the isolated IA-CGT contributes mainly to the IA-SRP and IA-CGT variations over the NH mid- and low-latitudes (to the south of 45°N). Furthermore, it is worth noting that the structures of the isolated IA-SRP and isolated IA-CGT are almost out-of-phase over the North Atlantic, North Pacific and North America in either the *V200* or *Z200* anomalies, which can explain the presentation of the weak and insignificant centers of the IA-SRP and IA-CGT over these areas (Figures 2a-b).

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b. Associations of the IA-SRP and IA-CGT with global climate and SST anomalies

Next, we investigate the links of the IA-SRP and IA-CGT as well as their independent parts to the NH summer precipitation, *Ts*, tropical and extra-tropical precipitation (heating), and global SST anomalies.

Corresponding to the IA-SRP and IA-CGT, the precipitation anomalies exhibit a similar structure that features a wave train pattern over the NH extra-tropics and a zonal dipole pattern over the tropics (Figures 4a-b). In the extra-tropics, reduced precipitation is observed over the western Europe, northern Russia, Meiyu-belt (from the Yangtze River to Korea and Japan), and North America, while enhanced precipitation is seen over the eastern Europe and the areas from the North China to the eastern Baikal. In the tropics, above-normal precipitation anomalies are observed over India, the North Indian Ocean and western North Pacific, and below-normal anomalies are apparent over the central-eastern tropical Pacific. The *Ts* anomalies associated with the IA-SRP display a wave train pattern over the mid-/high-latitude Eurasia, with warmer *Ts* over the western Europe, central Asia-to-northern Russia, and North America, but colder *Ts* over the eastern Europe, northwestern China-to-Baikal, and northeastern Russia (Figure 5a). The *Ts* anomalies in relation to the IA-CGT are characterized by an above-normal zonal pattern along the 30°N-45°N and a wavy structure to the north of 45°N, with warmer *Ts* over the western Europe, northeastern Russia and North America and colder *Ts* over the eastern Europe and Alaska (Figure 5b), but the *Ts* anomalies are weaker and less insignificant than those related to the IA-CGT. In addition, the IA-CGT also reveals a significant linkage to negative *Ts* anomalies observed over India and the eastern tropical Pacific, which are related to the positive ISM heating (Figure 4b) and La Niña-like SST anomalies (Figures 6e-g). The above distributions of the precipitation/*Ts* anomalies over the mid-/high-latitude NH are consistent with the circulation anomalies related to the IA-SRP and IA-CGT, respectively.

By contrast, the precipitation/*Ts* anomalies associated with the IA-SRP are stronger and more significant over the mid-/high-latitude Eurasia than those with the IA-CGT, while those associated with the IA-CGT are stronger and more significant over the ISM, tropical Indo-Pacific Ocean and East Asia. These features are more evident when removing the signal of each counterpart (Figures 4c-d and 5c-d). For example, the precipitation/*Ts* anomalies related to the isolated IA-SRP retain the main structures of those related to the IA-SRP and show clear intensification over the mid-/high-latitudes NH, but weaken evidently over the East Asian subtropics and shift to opposite anomalies over most parts of the ISM and tropical Indo-Pacific Oceans (Figures 4c and 5c). With respect to the isolated IA-CGT, the precipitation/*Ts* anomalies resemble those related to the IA-CGT, with stronger and more significant anomalies over most parts of the tropics and NH extra-tropics, except over the eastern Europe where positive precipitation/*Ts* anomalies are observed (Figures 4d and 5d). These features of the precipitation/*Ts* anomalies are opposite to, and have larger amplitude than those related to the isolated IA-SRP. From the above results, it can be concluded that the IA-SRP shows a stronger connection to the precipitation/*Ts* anomalies over mid-/high-latitude Eurasia, while the IA-CGT shows a stronger connection to the precipitation/*Ts* anomalies over the ISM, tropical Indo-Pacific Oceans and East Asia, which can be attributed to the isolated IA-SRP and isolated IA-CGT having a strong connection to the circulation anomalies over the northern and southern parts of Eurasia, respectively.

In addition, the precipitation/*Ts* anomalies related to the IA-SRP and IA-CGT, as well as their independent parts, feature a response to the La Niña-like or El Niño-like SST anomalies over the tropics (Figures 4a-b and Figures 5a-b). This indicates a linkage of the two IA teleconnection patterns to ENSO (Wu 2002; Ding and Wang 2005; Kosaka et al. 2009; Chen et al. 2012). To clarify the differences in their relationships with ENSO, the SST anomalies related to the IA-SRP and IA-CGT, as well as their independent parts, are investigated. As shown in Figures 6e-g, the IA-CGT shows a strong connection with the negative SST anomalies over the eastern Pacific, which resemble the SST anomaly evolutions of the developing phase of La Niña. This relationship becomes more evident after removing the IA-SRP signal. This is consistent with Ding and Wang (2005), who reported that the CGT tends to occur during La Niña developing summers. The La Niña-like SST anomalies favor a decrease in the precipitation/*Ts* over the tropical central-eastern Pacific and an increase in the

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precipitation/*Ts* over the ISM, Indian Ocean and western Pacific in relation to the (isolated) IA-CGT (Figures 4b, 4d, 5b and 5d). As for the IA-SRP, it shows a weak connection to the negative SST anomalies over the tropical eastern Pacific during summer and fall, consistent with Lu et al (2002). While, the isolated IA-SRP turns to connect strongly to the El Niño-like SST anomalies over the tropical eastern Pacific during summer and fall (Figures 6a-d), which are opposite to, and weaker than, the SST anomalies related to the isolated IA-CGT, corresponding to the precipitation/*Ts* anomalies over the tropical Indo-Pacific Oceans in relation to the (isolated) IA-SRP (Figures 4c and 5c).

The above results indicate that the (isolated) IA-CGT has a stronger connection to the ISM heating anomalies and ENSO than the (isolated) IA-SRP, which are considered as key external forcings for the IA-SRP/IA-CGT (Lu et al. 2002; Wu et al. 2002; Ding and Wang 2005). Regarding the (isolated) IA-CGT, the positive *Z200* anomalies over the central Asia (Figures 2b and 3d) feature a Gill-type Rossby wave response to the ISM heating forcing (Rodewell and Hoskins 1996; Wu 2002; Ding and Wang 2005; Enomoto et al. 2003), which can also be excited by divergent flow-induced vorticity advection due to the precipitation (heating) anomalies over the tropical Indian Ocean (Chen and Huang 2012). While the (isolated) IA-SRP shows a weak connection to the ISM heating, which may be largely attributed to the negative precipitation anomalies over the central-southern Europe (Yasui and Watanabe 2010; Lin et al. 2017). The roles of ENSO-like SST anomalies are significantly observed in the independent parts of the IA-SRP and IA-CGT. The El Niño-like and La Niña-like SST anomalies are responsible for the zonally negative and positive *Z200* anomalies related to the isolated IA-SRP and isolated IA-CGT, respectively (Figures 3c-d). There are two pathways for the La Niña-like SST anomalies affecting the isolated IA-CGT. The first pathway is that the heating anomalies related to La Niña-like SST anomalies can modulate the ISM through triggering the Walker circulation anomalies (figure not shown), which further excites an isolated IA-CGT-like wave train over Eurasia. The second pathway involves that the associated heating anomalies forcing a Pacific-North America (PNA) pattern that further excites a wave train over Eurasia and contributes to the isolated IA-CGT (Figures 2b and 3d). The two pathways can often coexist. The second pathway also works for the El Niño-like SST anomalies influencing the isolated IA-SRP. These results suggest that the IA-CGT is more like a tropical forcing-driven atmospheric mode, while the IA-SRP may be more like an internal atmospheric mode though it can be modulated by the mid-latitude disturbances, the ISM heating and ENSO.

c. Possible causes for the linkage and difference of the IA-SRP and IA-CGT

A natural question to ask is why the linkages and differences arise between the IA-SRP and IA-CGT, and what physical factors are responsible for their linkage and difference. Through further analysis, we find that the linkages and differences between the IA-SRP and IA-CGT are associated with their asymmetry relationship during their positive and negative phases, which are attributed to the asymmetry impacts of the ISM heating and ENSO on NH extra-tropical teleconnections. To verify this, an ISM precipitation index (ISMI) is defined to represent the ISM heating variability, which is the averaged precipitation anomalies over the domain (15°N–35°N; 60°–90°E), and the Niño3 index is used to denote ENSO, which is the averaged SST anomalies over the domain (5°S–5°N; 150°W–90°W). With a criterion of 0.5 standard deviations, the typical cases of the IA-SRP and IA-CGT indices and their configurations with the ISMI and Niño3 index are listed in Table 5. Also, a scatterplot between each pair of the IA-SRPI, IA-CGTI, ISMI and Niño3 index is displayed in Figure 7 to examine their relationship asymmetry. It can be seen that the IA-SRPI and IA-CGTI are more coherent during their co-positive years than during their co-negative years (Figure 7a), in which there are 9 co-positive cases and 5 co-negative cases. The correlation between them is 0.69 and 0.42 during the two kinds of years, respectively. These features are also supported by the composited *V200*/*Z200* anomalies based on their typical cases. As shown in Figures 8 and 9, the IA-SRP exhibits a symmetry wave train structure during its positive and negative phases. While the IA-CGT shows a weak symmetry structure, and features a similar pattern to the IA-SRP during its positive phase but a different pattern during its negative phase, with notable differences over the North Atlantic and Europe. This

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configuration makes the IA-SRP and IA-CGT more consistent during their positive phase than during their negative phase, corresponding to their linkages and differences, respectively.

It is also noticeable that during their strong linkage years, 7 out of the 9 co-positive cases coexist with positive ISM cases and 3 out of the 5 co-negative cases coexist with negative ISM cases (Table 4). This implies that the linkage between the IA-SRP and IA-CGT is closely related to the ISM heating in particular when the ISM heating is above normal. In addition, the scatterplot between the ISMI and the IA-SRPI and IA-CGTI also shows that the IA-SRP-ISM heating connection presents mainly during positive ISMI years (Figure 7b; with 9 co-positive; Table 5). Meanwhile the IA-CGT-ISM heating connection are evident during both positive and negative ISMI years (Figure 7d; with 12 co-positive and 10 co-negative cases; Table 5), which remains evident when excluding the typical IA-SRP cases (with 4 co-positive and 7 co-negative cases; Table 5), corresponding to the strong connection of the (isolated) IA-CGT to the ISM heating. The asymmetry connection of the ISM heating to the IA-SRP and IA-CGT results in the strong linkage between the two teleconnection patterns during their positive phase, and weak linkage during their negative phase.

To shed light on the asymmetry role of the ISM heating in linking the IA-SRP and IA-CGT, the *V200*/*Z200* anomalies regressed against the positive and negative phases of the ISMI are displayed in Figure 10. Here, the normalized ISMI with value of above and below 0.5 standard deviations is employed in the regression analyses, aming to clarify the asymmetry impact of the ISM heating on the Eurasian circulations. As shown in Figures 10a-b, the *V200*/*Z200* anomalies associated with the positive ISMI resemble those related to the positive IA-SRP/IA-CGT over Eurasia (to the south of 60°N), corresponding to the strong linkage between the IA-SRP and IA-CGT during positive ISMI years. While with respect to negative ISMI years, the associated *V200*/*Z200* anomalies feature a wave train pattern that is similar to the negative IA-CGT over its mid-/lower stream (to the east of 45°E) and resembles the negative isolated IA-CGT (Figures 8, 9 and 10c-d), showing a weak connection to the circulation anomalies over the North Atlantic and Europe. These results not only confirm the essential role of the positive ISM heating in linking the IA-SRP and IA-CGT, but also imply that the weak connection of the negative ISM heating to the circulation anomalies over the North Atlantic and Europe may be responsible for the difference between the IA-SRP and IA-CGT. The asymmetry responses of the Eurasian circulations to the positive and negative ISM heating may be associated with asymmetry distribution of the ISM heating during its two phases. As shown in Figure 11a-b, the precipitation anomaly center is situated prominently over the northwestern ISM when the ISM heating is above normal but over the northeastern ISM when the ISM heating is below normal. The westward shift of the ISM heating center may reduce its connection to the circulation anomalies over Europe and thereby weakens the linkage/coherence between the IA-SRP and IA-CGT, which is another topic of interest and will be examined in future work.

In addition to the essential role of the ISM heating, the ENSO may also contribute to the linkage and difference between the IA-SRP and IA-CGT. As listed in Table 4, 18 out of the total 41 typical IA-SRP and IA-CGT cases coexist with typcial ENSO cases, among which more typical ENSO cases coexist with individual IA-SRP or individual IA-CGT cases than with the co-typical cases of the IA-SRP and IA-CGT. This means that ENSO contributes largely to the difference between the two IA teleconnections. To confirm this, the *V200*/*Z200* anomalies regressed against the positive and negative Niño3 index (only the years in which the Niño3 index has values of above and below 0.5 standard deviations are used) are investigated. Given that the ENSO and the ISM heating show a strong negative relationship (with a correlation coefficient of −0.52 between them), in particular during La Niña phases (Figures 7f and 11c-d; Kumar et al. 2006), the years in which the ISMI has values of above and below 0.5 standard deviations are excluded in the regression analyses. As shown in Figure 12a-b, the *V200*/*Z200* anomalies associated with the El Niño are similar to the anomalies related to the isolated IA-SRP (Figures 3a-b). While the anomalies related to the La Niña feature a similar wave train pattern to the IA-SRP/IA-CGT, albeit the anomalies are insignificant (Figures 12c-d). This means that the La Niña, which often coexists with positive ISM heating, is conducive to the linkage between the IA-SRP and IA-CGT, while the El Niño contributes to the difference between them. In contrast to the ISM heating, ENSO plays a secondary role in the linkages and differences between the IA-SRP and IA-CGT.

To sum up, the IA-SRP and IA-CGT reveal clear independences. The isolated IA-SRP and isolated IA-CGT mainly represent the mid-/high-latitude-related and tropics-related parts of the NH upper tropospheric circulation variations, respectively. Accordingly, the IA-SRP and IA-CGT show a strong connection to the summer climate variations over the northern and southern parts of the NH mid-/high-latitudes, respectively. These differences result from the asymmetry relationship between the IA-SRP and IA-CGT during their postive and negative phases, which are mainly attributed to the asymmetry impact of the positive and negative ISM heating on the Eurasian circulations. The ENSO also contributes to the linkages and differences between the IA-SRP and IA-CGT, but plays a secondary role.

4.2. Relationship between the SRP and CGT on the ID timescale

a. Independent parts of the ID-SRP and ID-CGT

Here, we investigate the independences between the ID-SRP and ID-CGT. In the *V200* anomalies, the isolated ID-SRP retains the major wave train of the ID-SRP over the North Atlantic and Eurasia (Figure 13a). While, the isolated ID-CGT keeps the major structure of the ID-CGT over Korea-Japan, the North Pacific and North America but exhibits an opposite pattern to the ID-CGT and isolated ID-SRP over Eurasia (Figure 13b). The spatial correlation coefficients of the ID-SRP and ID-CGT with their isolated counterparts are 0.73 and 0.34, respectively. In the *Z200* anomalies, the isolated ID-SRP retains the major wave train pattern of the ID-SRP, especially over Eurasia, albeit its positive centers are much weaker (Figure 13c). The spatial correlation coefficient between them is about 0.61. As for the isolated ID-CGT, it reveals almost an opposite pattern to the isolated ID-SRP with positive *Z200* anomalies over most parts of the NH. However, its positive centers almost overlapp with those of the ID-CGT (Figure 13d). The spatial correlation coefficient between the ID-CGT and isolated ID-CGT is approximately 0.51. By contrast, the isolated ID-SRP keeps a larger portion of the ID-SRP/ID-CGT variations over Eurasia than the isolated ID-CGT over the mid-/high-latitude Eurasia (to the north of 45°N), while the isolated ID-CGT retains a larger portion of the ID-SRP and ID-CGT over the lower-latitude Eurasia (to the south of 45°N). These features are similar to those related to the IA-SRP and IA-CGT. In addition, it should be noted that the ID-SRP and ID-CGT feature a combined result of the isolated ID-SRP and isolated ID-CGT, while the isolated ID-SRP and isolated ID-CGT exhibit nearly an opposite structure over most parts of the NH (160°E–360°W) except for Eurasia, with spatial correlation coefficients of −0.62 and −0.60 in the *V200* and *Z200* anomalies, respectively. This is why the ID-SRP and ID-CGT are stronger and more significant over Eurasia than over other parts of the NH.

b. Associations of the ID-SRP and ID-CGT with global climate and SST anomalies

Figures 14 and 15 illustrate the precipitation and *Ts* anomalies corresponding to the ID-SRP and ID-CGT as well as their independent parts. Both the ID-SRP and ID-CGT are accompanied by similar precipitation anomalies over the mid-/high-latitude Eurasia, with positive anomalies over the eastern Europe and eastern Siberia and negative anomalies over the western Europe, northern Russia and subtropical East Asia along the Meiyu-belt (Figures 14a-b). The associated *Ts* anomalies also exhibit similar structures, with negative anomalies over Europe and eastern Siberia and warm *Ts* over the North India, West Asia and North Russia (Figures 15a-b). The distributions of the precipiation and *Ts* anomalies show a good correspondence with the circulation anomalies related to the ID-SRP and ID-CGT. In addition, the ID-SRP and ID-CGT also reveal a certain connection to the precipitation/*Ts* anomalies over the tropics, albeit the anomalies are statistically insignificant. For example, both the ID-SRP and ID-CGT are accompanied by enhanced precipitation over the ISM and central Pacific and reduced precipitation over the tropical Atlantic, southeastern Indian Ocean and eastern Pacific (Figures 14a-b). As for the *Ts* anomalies, significant positive anomalies are observed over the eastern tropical Pacific, and significant negative *Ts* anomalies are seen over the North Pacfic (Figures 15a-b), which together feature a PDO-like pattern that may be associated with the positive PDO-like SST anomalies related to the two ID teleconnection patterns (see the results in Figure 16).

The precipitation/*Ts* anomalies associated with the isolated ID-SRP retain the major structures of thoses related to the ID-SRP, which have more significant and stronger anomalies over the tropics and NH extra-tropics, except for the West Asia (to the west of the Balkashi Lake) and North India (Figures 14c and 15c), where the anomalies weaken evidently. The precipitation/*Ts* anomalies related to the isolated ID-CGT differ largely from those related to the ID-CGT, which feature nearly opposite patterns to those related to the isolated ID-SRP, except for the precipitation anomalies over the eastern Indian Peninsula and the *Ts* anomalies over North India (Figures 14d and 15d). The anti-phase precipitation/*Ts* anomalies related to the isolated ID-SRP and isolated ID-CGT are responsible for the statistically insignificant precipitation/*Ts* anomalies associated with the ID-SRP and ID-CGT over most parts of the tropics and NH extra-tropics.

Previous studies have shown that the ID-SRP and ID-CGT are modulated by the ID SST anomalies over the North Atlantic and North Pacific (Wu et al. 2016; Wang et al. 2017; Stephan et al. 2019). As shown in Figure 16, the ID-SRP and ID-CGT tend to occur during the positive phase of the PDO and the negative phase of the AMO, particularly during summer. The correlation coefficients of the ID-SRPI/ID-CGTI with the summer PDO and AMO indices on the ID timescale are 0.65/0.56 and −0.54/−0.45, respectively. The confidence levels for the four correlation coefficients are respectively 94%, 88%, 89% and 81%. When removing the signal of the each counterpart, the PDO-like and AMO-like SST anomalies remain during summer in relation to the isolated ID-SRP but disapper in relation to the ID-CGT. From this perspective, the PDO and AMO are more likely the driving factors of the ID-SRP. This is to some extent consistent with previous studies on the linkages of the PDO and AMO to the ID circumglobal wave train over the NH, which resembles the ID-SRP despite these studies having adopted the name of ID-CGT (Zhu et al. 2015; Si and Ding 2016; Stephan et al. 2019). Besides, Stephan et al. (2019) documented that the ID SST anomalies over the North Atlantic and the North Pacific may indirectly influence the SRP by modulating the ISM precipitation anomalies. However, the present study identifies a weak connection between the ID-SRP and ISM heating during 1961-2018. This discrepancy may be due to the different periods (1900-2016) used in their study.

The independences of the ID-SRP and ID-CGT and their associations with global climate and SST anomalies are not as well organzied as their IA counterparts, which makes it hard to clarify what factors are responsible for their differences. This is due to the high spatial and temporal correlations (with value of 0.97 and 0.88, respectively) between the ID-SRP and ID-CGT, which implies that the ID-SRP and ID-CGT are more likely the same teleconnection pattern, in particular over Eurasia.

Conclusions and discussion

The SRP and CGT are two well-known teleconnection patterns along the Eurasian westerly jet during boreal summer. Due to their highly spatial-temporal similarity, the SRP and CGT are often regarded as one teleconnection pattern. Given the distinct features of the SRP and CGT on the IA and ID timescales, the present work investigates the linkages and differences between the SRP and CGT on the IA and ID timescales, with the aim to provide a comprehensive view of the SRP–CGT relationship. The main results are summarized as follows.

In total, the SRP and CGT exhibit a circumglobal wave train structure along the NH westerly jet, and have five/four significant and strong active centers over Eurasia in terms of the *V200*/*Z200* anomalies. They are more coherent in the *V200* anomalies than in the *Z200* anomalies. Both the SRP and CGT reveal clearly IA, ID and long-term trend variations. And they represent largely the IA variability of the upper-tropospheric circulation anomalies over Eurasia. The IA-SRP and IA-CGT account for respectively about 57% and 69.8% of the total variance of the SRP and CGT, while the ID components of the SRP and CGT explain approximately 13.4% and 15.9% of the total variance of the two teleconnection patterns, respectively.

On the IA timescale, the SRP and CGT exhibit a clearly and coherently circumglobal wave train over the NH mid-latitudes, with significant and strong active centers over Eurasia. They reveal high spatial-temporal similarity, with spatial correlation coefficient beyond 0.8 and temporal correlation coefficient of about 0.72. As for their independent parts, the isolated IA-SRP retains the IA-SRP

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structure and shows a strong impact on the summer climate over the northern part of the mid-/high-latitude NH (to the north of about 45°N). While the isolated IA-CGT reserves the major structure of the IA-CGT and has a strong impact on the summer climate over the southern part of the NH mid-latitudes (to the south of about 45°N). The isolated IA-CGT shows a stronger connection to the ISM heating and ENSO than the isolated IA-SRP. This makes the IA-CGT more like a tropical forcing driven atmospheric mode, while the IA-SRP is more like an internal atmospheric mode though it can be modulated by the mid-latitude disturbances, ISM heating and ENSO. From this aspect, the IA-SRP and IA-CGT may represent largely the mid-/high-latitude-related and tropics-related parts of the NH upper tropospheric circulation variations, respectively, which may often coexist and result in the prominent teleconnection pattern over Eurasia.

The linkages and differences between the IA-SRP and IA-CGT are respectively corresponding to their strong and weak coherence during their positive and negative phases, which are mainly attributed to the asymmetry impact of the ISM heating on the two teleconnection patterns. Positive ISM heating favors a linkage between the IA-SRP and IA-CGT by triggering a positive IA-SRP-like/IA-CGT-like wave train pattern over the area from the North Atlantic, Europe and Asia. Negative ISM heating shows a weak impact on the European circulations and often excites a wave train pattern over the area from the North Africa to East Asia, which the features a negative IA-CGT-like pattern, contributing to the difference between the IA-SRP and IA-CGT. ENSO plays a secondary role in the linkages and differences between the IA-SRP and IA-CGT, with the El Niño contributing to their differences and the La Niña to their linkages.

On the ID timescale, both the ID-SRP and ID-CGT feature a two-wave train structure over Eurasia, with one weak wave train and another prominent wave train located to the south and north of 45°N, respectively. They bear a high spatial-temporal similarity, with spatial and temporal correlation coefficients of 0.97 and 0.88, respectively. These features make the ID-SRP and ID-CGT more like the same teleconnection pattern, in particular over Eurasia. In addition, the ID-SRP shows a stronger connection to the PDO and AMO than the ID-CGT. This means that the PDO and AMO are more likely the driving factors of the ID-SRP.

It should be noted that the present findings regarding the the SRP–CGT relationship on the IA and ID timescales are different from those of Zhou et al (2019), who regarded the CGT as a section of the SRP. This discrepancy is due to that they overlooked the distinction between the SRP and CGT on the IA and ID timescales, as well as the impact of the linear trend on their ID variations. More importantly, the clear differences between the IA-SRP and IA-CGT in their structures, associations with Eurasian summer climate, the ISM heating and ENSO imply that the IA-SRP and IA-CGT should be regarded as two different teleconnection patterns, albeit they bear a high spatial similarity. Also, these differences make the prediction of the SRP or CGT variations much difficult, as argued by Kosaka et al. (2011), who stated that the contemporary initialized coupled prediction systems cannot achieve a reliable prediction of the SRP phase at monthly to seasonal lead times. In addition, the present study indicates that the linear trends of the SRPI and CGTI affect largely the ID variations of the SRP and CGT, which show clear decreasing trends since the late-1980s or the early-1990s (Figures 1c-f). This implies a weakening trend of the SRP/CGT, which may be associated with the anghropogenic global warming as documented in Lee et al. (2014). The present findings on the linkages and differences between the SRP and CGT, in particular on the IA timescale, are beneficial to understanding the variability and prediction of the SRP and CGT, which have important implications for seasonal climate prediction over the NH extra-tropics.

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References

1. Chen, G., and R. Huang, 2012: Excitation mechanisms of the teleconnection patterns affecting the July precipitation in Northwest China. J. Clim., 25, 7834–7851.
2. ——, ——, and L. Zhou, 2013: Baroclinic Instability of the Silk Road Pattern Induced by Thermal Damping. J. Atmos. Sci., 70, 2875–2893.
3. Chen, M., P. Xie, J. E. Janowiak, and P. A. Arkin, 2002: Global Land Precipitation: A 50-yr Monthly Analysis Based on Gauge Observations. J. Hydrometeor., 3, 249–266.
4. Ding, Q., and B. Wang, 2005: Circumglobal teleconnection in the Northern Hemisphere summer. J. Clim., 18, 3483–3505.
5. ——, ——, J. M. Wallace, and G. Branstator, 2011: Tropical-extratropical teleconnections in boreal summer: Observed interannual variability. J. Clim., 24, 1878–1896.
6. Duchon, C. E., 1979: Lanczos Filtering in One and Two Dimensions. J. Appl. Meteor., 18, 1016–1022.
7. Enomoto, T., 2004: Interannual variability of the Bonin high as- sociated with the propagation of Rossby waves along the Asian jet. J. Meteor. Soc. Japan, 82, 1019–1034.
8. ——, B. J. Hoskins, and Y. Matsuda, 2003: The formation mechanism of the Bonin high in August. Q. J. R. Meteorol. Soc., 129, 157–178.
9. Gong, Z., G. Feng, M. M. Dogar, and G. Huang, 2018: The possible physical mechanism for the EAP–SR co-action. Clim. Dyn., 51, 1499–1516.
10. Hong, X.-W., S.-H. Xue, R.-Y. Lu, and Y.-Y. Liu, 2018: Comparison between the interannual and decadal components of the Silk Road pattern. Atmos. Ocean. Sci. Lett., 1–5.
11. Hong, X., R. Lu, and S. Li, 2017: Amplified summer warming in Europe-West Asia and Northeast Asia after the mid-1990s. Environ. Res. Lett., 12, doi:10.1088/1748-9326/aa7909.
12. Huang, G., Y. Liu, and H. Ronghui, 2011: The Interannual Variability of Summer Rainfall in the Arid and Semiarid Regions of Northern China and Its Association with the Northern Hemisphere Circumglobal Teleconnection.pdf. Adv. Atmos. Sci., 28, 257–268.
13. Huang, R. H., Y. Liu, and T. Feng, 2013: Interdecadal change of summer precipitation over Eastern China around the late-1990s and associated circulation anomalies, internal dynamical causes. Chinese Sci. Bull., 58, 1339–1349.
14. Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, and L. Gandin, 1996: The NCEP / NCAR 40-Year Reanalysis Project. Bull. Am. Meteorol. Soc., 77.
15. Kosaka, Y., and H. Nakamura, 2010: Mechanisms of meridional teleconnection observed between a summer monsoon system and a subtropical anticyclone. Part I: The Pacific-Japan pattern. J. Clim., 23, 5085–5108.
16. ——, ——, M. Watanabe, and M. Kimoto, 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. Meteorol. Soc. Japan, 87, 561–580.
17. ——, S. P. Xie, and H. Nakamura, 2011: Dynamics of interannual variability in summer precipitation over East Asia. J. Clim., 24, 5435–5453.
18. Kumar, K. Krishna, B. Rajagopalan, M. Hoerling, G. Bates, and M. Cane, 2006: Unraveling the Mystery of Indian Monsoon Failure During El Niño. *Science*, **314**, 115-119.
19. Lin, Z., and R. Lu, 2016: Impact of summer rainfall over southern-central Europe on circumglobal teleconnection. Atmos. Sci. Lett., 17, 258–262.
20. ——, ——, and R. Wu, 2017: Weakened impact of the Indian early summer monsoon on north China rainfall around the late 1970s: Role of basic-state change. J. Clim., 30, 7991–8005.
21. Liu, Y., and R. Huang, 2019: Linkages between the South and East Asian Monsoon water vapor transport during boreal summer. J. Clim., JCLI-D-18-0498.1.
22. ——, R. Wu, and W. Zhou, 2019: A new perspective on the interdecadal change of the Silk Road pattern around the late-1970s. submitted to J. Clim., Major revision.
23. Lu, R. Y., J. H. Oh, and B. J. Kim, 2002: A teleconnection pattern in upper-level meridional wind over the North African and Eurasian continent in summer. Tellus, Ser. A Dyn. Meteorol. Oceanogr., 54, 44–55.
24. Metz, W., 1991: Optimal Relationship of Large-Scale Flow Patterns and the Barotropic Feedback Due to High-Frequency Eddies. J. Atmos. Sci., 48, 1141–1159.
25. Rayner, N. A., 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. J. Geophys. Res., 108, 4407.
26. Sato, N., and M. Takahashi, 2006: Dynamical processes related to the appearance of quasi-stationary waves on the subtropical jet in the midsummer northern hemisphere. J. Clim., 19, 1531–1544.
27. Seager, R., N. Harnik, Y. Kushnir, W. Robinson, and J. A. Miller, 2003: Mechanisms of hemispherically symmetric climate variability. J. Climate, 16, 2960–2978.
28. Si, D., and Ding, Y., 2016: Oceanic forcings of the interdecadal variability in east Asian summer rainfall. J. Clim., 29(21), 7633–7649.
29. Stephan, C. C., N. P. Klingaman, and A. G. Turner, 2019: A mechanism for the interdecadal variability of the Silk Road Pattern. J. Clim., 32, 717–736.

 doi:10.20944/preprints202309.1661.v1

30. Trenberth, K. E., G. W. Branstator, D. Karoly, A. Kumar, N. Lau, and C. Ropelewski, 1998: Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. J. Geophys. Res., 103, 14291–14324.
31. Wang, H., F. Huang and Y. X. Yang, 2013: Reanalysis on the interdecadal variability of the circumglobal teleconnection (in Chinese). Journal of Ocean University of China, 43, 1-8.
32. Wang, H., B. Wang, F. Huang, Q. Ding, and J. Y. Lee, 2012: Interdecadal change of the boreal summer circumglobal teleconnection (1958-2010). Geophys. Res. Lett., 39, doi:10.1029/2012GL052371.
33. Wang, L., P. Xu, W. Chen, and Y. Liu, 2017: Interdecadal variations of the Silk Road pattern. J. Clim., 30, 9915–9932.
34. Wu, B., J. Lin, and T. Zhou, 2016: Interdecadal circumglobal teleconnection pattern during boreal summer. Atmos. Sci. Lett., 17, 446–452.
35. Wu, R., 2002: A mid-latitude Asian circulation anomaly pattern in boreal summer and its connection with the Indian and East Asian summer monsoons. Int. J. Climatol., 22, 1879–1895.
36. ——, and B. Wang, 2002: A contrast of the East Asian summer monsoon-ENSO relationship between 1962-77 and 1978-93. J. Clim., 15, 3266–3279.
37. Yasui, S., and M. Watanabe, 2010: Forcing processes of the summertime circumglobal teleconnection pattern in a dry AGCM. J. Clim., 23, 2093–2114.
38. Zhou, F., R. Zhang, and J. Han, 2019: Relationship between the Circumglobal Teleconnection and Silk Road Pattern over Eurasian continent. Sci. Bull., 64, 374–376.
39. Zhu, Y., Wang, H., Ma, J., Wang, T., and Sun, J., 2015: Contribution of the phase transition of Pacific Decadal Oscillation to the late 1990s' shift in East China summer rainfall. J. Geophys. Res., 120(17), 8817–8827.