Comparison between the interannual and decadal components of the Silk Road pattern

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ABSTRACT

The Silk Road pattern (SRP), which is a teleconnection pattern along the Asian upper-tropospheric westerly jet in summer, exhibits both interannual and decadal variabilities. Through the nine-year Gaussian filtering method and regression analyses, this study examines the interannual and decadal components of the SRP. The results indicate that the interannual SRP corresponds to a well-organized wave train of alternate cyclonic and anticyclonic anomalies across the Eurasian continent along the Asian westerly jet, resulting in a similar wave-like pattern of cold and warm surface temperature anomalies. This pattern of temperature anomalies differs from that associated with the original SRP, which is characterized by warmer or cooler temperatures mainly over Europe–West Asia and Northeast Asia, but weak anomalies tend to be weak over East Asia. These circulation anomalies are responsible for the significant temperature anomalies over Europe–West Asia and Northeast Asia but weak anomalies between these two domains.

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1. Introduction

The Silk Road pattern (SRP), which has been demonstrated to be the leading mode of the upper-tropospheric meridional wind anomalies in summer (Chen and Huang 2012; Hong and Lu 2016; Kosaka et al. 2009; Sato and Takahashi 2006), indicates a teleconnection pattern along the Asian westerly jet (Lu, Oh, and Kim 2002). It is manifested by alternate meridional wind anomalies over the midlatitude Eurasian continent (e.g. Chen and Huang 2012; Enomoto, Hoskins, and Matsuda 2003; Hong and Lu 2016; Kosaka et al. 2009; Sato and Takahashi 2006). This pattern is similar to the circumglobal teleconnection (CGT) (e.g. Ding and Wang 2005; Ding et al. 2011) over the Eurasian continent.

With a broad scope from Europe to East Asia, the SRP exerts great influences on climate (e.g. Enomoto 2004; Hong, Lu, and Li 2017; Huang, Liu, and Huang 2011; Lu, Oh, and Kim 2002; Ogasawara and Kawamura 2007; Su and Lu 2014). Most previous studies obtained the SRP by analyzing original data, assuming that the interannual component is the overwhelming majority of the SRP (e.g. Enomoto, Hoskins, and Matsuda 2003; Hong and Lu 2016; Kosaka et al. 2009; Lu, Oh, and Kim 2002; Sato and Takahashi 2006; Song, Zhou, and Wang 2013). However, some recent studies have shown that the SRP has a considerable decadal component (Hong, Lu, and Li 2017; Wang et al. 2017). Hong, Lu, and Li (2017) suggested that this decadal component
plays a substantial role in the amplified warming over Europe–West Asia and Northeast Asia after the mid-1990s. Wang et al. (2017) analyzed both the interannual and decadal components of the SRP, using several reanalysis and observational datasets. However, both studies paid more attention to the decadal component and ignored a careful comparison between interannual and decadal components, which is the aim of the present study.

## 2. Datasets and methods

The main datasets used in this study are the monthly circulation variables from the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis products (Kalnay et al. 1996), with a horizontal resolution of $2.5\degree \times 2.5\degree$. Also used are the monthly land surface temperature data from the Climatic Research Unit (version 3.24) (Harris et al. 2014), with a high horizontal resolution ($0.5\degree \times 0.5\degree$) based on weather station records, and the extended reconstructed monthly SST data ($2\degree \times 2\degree$ horizontal resolution; version 5) (Smith et al. 2008) from the National Oceanic and Atmospheric Administration. In this study, the time span is 1958–2015 for the land surface temperature and 1958–2017 for all other datasets. The June–July–August average is used to represent the summer season.

Following Yasui and Watanabe (2010), the SRP is obtained by applying empirical orthogonal function (EOF) analysis to the raw 200-hPa meridional wind ($V_{200}$) anomalies within the domain (20°–60°N, 0°–150°E), and determining the leading mode. The principal component of this leading mode (PC1) is then taken as the SRP index (SRPI) to quantify the SRP. This mode explains 27.6% of the total variance for the $V_{200}$ anomalies and can be well separated from the second mode (12.3%). For convenience of discussion, a positive phase of the SRP is defined when there are southerly anomalies over the Caspian Sea and the SRPI is positive.

The decadal component is determined by applying the nine-year Gaussian filtering method onto the original sequence, for either the SRPI or the variables used in this study. The interannual component is regarded as the difference between the raw sequence and the decadal component.

The main statistical tool in this study is regression analysis, and the Student’s $t$-test is used to test the significance. The effective degrees-of-freedom are considered when analyzing the decadal variability, based on Metz (1991) and Livezey (1995).

## 3. Results

Figure 1(a) shows the $V_{200}$ anomalies regressed onto the standardized SRPI. The anomalies appear as a clear wave-like pattern across the midlatitude Eurasian continent, characterized by alternate southerly and northerly anomalies along the Asian westerly jet, consistent with various previous studies (e.g. Chen and Huang 2012; Hong and Lu 2016; Kosaka et al. 2009; Lu, Oh, and Kim 2002; Sato and Takahashi 2006; Yasui and Watanabe 2010). Almost all anomalies of the major part for the wave pattern are statistically significant, and their centers confined approximately within 30°–60°N. Amplitudes of the anomalous centers tend to be similar, manifested by the value of each center being about 2.5 m s$^{-1}$.

The time series of the SRPI is shown as the bars in Figure 1(b). It seems that the SRPI features both year-to-year variability and a long-term variability. Actually, the interannual component of the SRPI (Figure 1(c); hereafter, SRPI-I), which is determined as the difference between the original SRPI (bars in Figure 1(b)) and the decadal component, features both year-to-year variability and a long-term variability.
component of SRPI (SRPI-D; solid line in Figure 1(b)), accounts for 58.5% of the total variance of SRPI. On the other hand, the SRPI-D explains 28.2% of the total variance and has a phase change in the mid-1990s, in agreement with Hong, Lu, and Li (2017).

Figure 2 shows the V200 anomalies regressed onto the standardized SRPI-I and SRPI-D, separately. Both distributions of the anomalies present a wave-like pattern. However, these two patterns are markedly distinct from one another. The anomalies related to the SRPI-I (Figure 2(a)) bear a close resemblance to those related to the overall SRP (Figure 1(a)). Whereas, the anomalies related to the SRPI-D (Figure 2(b)) are similar to the interannual ones from Europe to Central Asia, but much weaker over East Asia.

Differences between the interannual and decadal SRP can also be illustrated by the 200-hPa geopotential height (Z200) anomalies regressed onto the standardized SRPI-I and SRPI-D, respectively, as shown in Figure 3. Corresponding to the SRPI-I (Figure 3(a)), significant positive and negative anomalies form a clear wave-like pattern along the Asian jet, from Europe to East Asia. The strongest positive anomalies appear over West Asia. There are also significant negative anomalies over Europe and Central Asia, and positive anomalies over East Asia. These positive and negative anomalies are consistent with the V200 anomalies shown in Figure 2(a). By contrast, the anomalies related to the SRPI-D (Figure 3(b)) are overwhelmed by the significant negative anomalies over Europe and Central Asia, leaving the positive anomalies between them much compressed and quite weak. In addition, the positive anomaly over Northeast China and the Korean peninsula, which is significant for the SRP-I (Figure 3(a)), cannot be found for the SRP-D (Figure 3(b)).

There is a significant negative Z200 anomaly over the Russian Far East in Figure 3(b), whilst the V200 anomalies here are very weak (Figure 2(b)). This negative anomaly may have little connection with the SRP, since it is located far away from the Asian westerly jet. Actually, this anomaly may be a circulation response to the enhanced rainfall in South China, according to the result of Kwon, Jhun, and Ha (2007), who suggested that the increased precipitation over South China after the mid-1990s can trigger an anomalous anticyclone over the Russian Far East domain (Figure 2(b) in their paper). This coincidence might result from the fact that the time for decadal change in South China rainfall, i.e. the mid-1990s, happens to be close to the phase turning point of the SRPI-D. Therefore, we suggest that this cyclonic anomaly over the Russian Far East should not be associated with the SRPI-D.

It is interesting that the distribution of Z200 anomalies related to the decadal SRP (Figure 3(b)) is similar to that

![Figure 2](image1.png)  ![Figure 3](image2.png)

**Figure 2.** The 200-hPa meridional wind (V200) anomalies (contours; units: m s⁻¹) regressed onto the standardized (a) SRPI-I on the interannual time scale and (b) SRPI-D on the decadal time scale.

**Figure 3.** The 200-hPa geopotential height (Z200) anomalies (contours; units: m) regressed onto the standardized (a) SRPI-I on the interannual time scale and (b) SRPI-D on the decadal time scale.

Notes: Contour intervals are 0.5 m s⁻¹ and zero contours are omitted. Solid and dashed contours indicate positive and negative anomalies, respectively. Shading indicates regions of significance at the 0.05 level, and the effective degrees-of-freedom have been considered in (b), according to the Student’s t-test. The bold line delineates the climatological jet axis.
related to the CGT (Ding and Wang 2005; Figure 1(b) and (c)), while the CGT is an interannual variation. Both distributions show two significant action centers over the western and eastern Eurasian continent, but between them the anomalies are much compressed and quite weak. On the other hand, there are some distinctions between the two distributions. For instance, the main action centers related to the decadal SRP are generally situated more westward than those to the CGT, with a longitudinal difference of about 30°, indicating that the decadal SRP and CGT are essentially different.

Figure 4 shows the surface temperature anomalies regressed onto the standardized SRPI-I and SRPI-D, respectively. There is a good correspondence between the circulation and temperature anomalies in terms of both their strength and geographic position. The temperature anomalies related to the SRPI-I (Figure 4(a)) are characterized by a well-organized wave train of alternate cold and warm anomalies from Europe to East Asia. These significant cold and warm anomalies coincide well with the cyclonic and anticyclonic circulation anomalies (Figures 2(a) and 3(a)). It should be noted that the positive temperature anomalies to the east of the Caspian Sea and over East Asia are prominent and statistically significantly associated with the SRPI-I (Figure 4(a)), while they seem to be very weakly associated with the overall SRP (Hong and Lu 2016, Figure 5(b)). This difference makes the wave-like pattern clearer for the SRPI-I-related anomalies, and indicates the need to investigate the interannual and decadal components of the SRP separately. Corresponding to the SRPI-D (Figure 4(b)), significant temperature anomalies exist over the midlatitude western and eastern Eurasian continent, but are very weak between, coinciding with the significant negative Z200 anomalies and weak positive anomalies over these domains.

We repeated the above analyses using JRA-55 data (Kobayashi et al. 2015), and obtained very similar results (figures not shown), confirming the robust features of the interannual and decadal SRP.

4. Conclusions

Using datasets with a time span of 1958–2017, the present study compares the interannual and decadal components of the SRP. Results show that the circulation anomalies related to the interannual component show a well-organized wave-like pattern across the midlatitude Eurasian continent along the Asian westerly jet. Accordingly, alternate warm and cold temperature anomalies appear at the surface beneath these anticyclonic and cyclonic anomalies. On the other hand, the meridional wind anomalies related to the decadal part of the SRP show a similar distribution to the interannual situation from Europe to Central Asia, but are very weak over East Asia. There is also a significant cyclonic anomaly over the Russian Far East, but this may not be related to the decadal component of the SRP.

Dynamically consistent with these circulation anomalies, the surface temperature anomalies related to the two components of the SRP are also distinct from each other (Figure 4). The interannual SRP corresponds to alternate cold and warm anomalies over the midlatitude Eurasian continent, coinciding well with the wave train of cyclonic and anticyclonic circulation anomalies. The warm anomalies over West Asia and East Asia are stronger and more significant (Figure 4(a)) than those related to the overall SRP in Hong and Lu (2016). On the other hand, the temperature anomalies corresponding to the decadal part of the SRP (Figure 4(b)) are significant and negative over Europe–West Asia and Northeast Asia, but seem very weak between these two domains, closely coherent with the significant negative Z200 anomalies and weak positive anomalies.

The present results show that the anomalies related to the interannual component of the SRP exhibit a much clearer wave train in comparison with the anomalies associated with the overall SRP, i.e. without removing the decadal component. This wave train can be explained well by Rossby wave ray theory (Hoskins and Ambrizzi 1993). However, the mechanism for the decadal variation of the SRP remains unclear. Considering the possibility of
different mechanisms being responsible for the interannual and decadal variabilities of the SRP, it would be better to distinguish these two kinds of variabilities in future studies.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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