Combined impact of the Pacific–Japan pattern and Mediterranean–northern Eurasia pattern on East Asian summer temperatures

MING Jing\textsuperscript{a,b}, SUN Jianqi\textsuperscript{a,b,c} and YU Shui\textsuperscript{a,b}

\textsuperscript{a}Nansen-Zhu International Research Center, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China; \textsuperscript{b}College of Earth and Planetary Sciences, University of Chinese Academy of Sciences, Beijing, China; \textsuperscript{c}Joint Laboratory for Climate and Environmental Change, Chengdu University of Information Technology, Chengdu, China

ABSTRACT

The combined effect of the Pacific–Japan (PJ) pattern and Mediterranean–northern Eurasia (MnE) pattern on East Asian surface air temperature (SAT) during summer is investigated using the Japanese 55-year reanalysis and Climatic Research Unit SAT data over the period of 1958–2016. The results show that the combination of the two patterns in different phases can result in different SAT anomalies. During the in-phase PJ-MnE years, the overlapping of opposite signs of the atmospheric circulations associated with the PJ and MnE patterns results in weak atmospheric circulation and SAT anomalies in central East Asia; during these years, the significant SAT anomalies are over northern East Asia. In contrast, during the out-of-phase PJ-MnE years, the overlapping of the same signs of the atmospheric circulations associated with the PJ and MnE patterns leads to significant atmospheric circulation and SAT anomalies in central East Asia and northern Asia. The analysis in this study indicates that to better understand and predict the variability of East Asian summer SATs, the combined effect of the PJ and MnE patterns should be taken into account.

PJ和MnE遥相关型对东亚夏季气温的协同影响

摘要

本文研究发现太平洋-日本遥相关型（PJ）和地中海-欧亚北部遥相关型（MnE）对东亚夏季气温存在显著的协同影响。当PJ和MnE处于同位相时，两者相关的大气环流在东亚中东部地区相互叠加，而此时显著的气温异常主要位于东亚北部。相反，当PJ和MnE处于反位相时，两者相关的大气环流在东亚地区相互叠加增强，从而对东亚中东部和亚洲北部地区的气温产生显著影响。因此，在东亚夏季气温变化的理解与预测中需要考虑这两个遥相关的协同作用。

1. Introduction

Previous studies have shown that East Asian summer surface air temperature (SAT) is controlled by various local atmospheric circulations: the western Pacific subtropical high (Cui et al. 2007; Wang et al. 2016; Gao et al. 2018), the upper-level westerly jet (Lu, Lin, and Zhang 2013; Sun 2014; Lin et al. 2018), and the Okhotsk high (Ninomiya and Mizuno 1985; Sato and Takahashi 2007). The combination of these large-scale atmospheric circulations can be represented by the Pacific–Japan (PJ) teleconnection pattern (Choi, Wu, and Cha 2010). Therefore, the PJ pattern (Nitta 1987, 1989) or East Asia–Pacific pattern (Huang and Sun 1992), is the dominant atmospheric mode, having considerable impact on summer rainfall and temperature over the region (e.g. Huang and Sun 1992; Wakabayashi and Kawamura 2004; Yasunaka and Hanawa 2006; Kosaka et al. 2013). In addition to exerting a direct impact, the PJ pattern also serves as a bridge to transport other remote factors of influence to East Asia. For example, the effects of ENSO and Indian Ocean SST on the East Asian summer climate are related to the PJ pattern (Huang et al. 2004; Sun et al. 2010; Kosaka et al. 2013; Xie et al. 2016).

Although these previous studies have indicated that the PJ pattern exerts a dominant impact on the East Asian summer climate, which further helps to improve the prediction of the East Asian summer climate, in some years an anomalous PJ pattern does not lead to anomalous East Asian summer climate (e.g. Hsu and Lin 2007; Ogasawara and Kawamura 2007), which indicates that there could be some other factors balancing the impact of the PJ pattern on East Asian summer climate.
The East Asian summer climate is not only directly impacted by the PJ-like meridional teleconnection pattern, but also influenced by the zonal teleconnection pattern over Eurasia (e.g. Wu 2002; Lu, Oh, and Kim 2002; Enomoto 2004; Ding and Wang 2005; Huang, Liu, and Huang 2011; Huang, Liu, and Feng 2013; He, Liu, and Wang 2017; Wang et al. 2017). For the Eurasian zonal teleconnection pattern, the Mediterranean region is special because of its location over the entrance of the Eurasian upper-level westerly jet. Dynamics-based studies have indicated that the upper-level westerly jet is the Rossby waveguide, determining the wave train propagation (e.g. Hoskins and Ambrizzi 1993; Ambrizzi, Hoskins, and Hsu 1995; Sato and Takahashi 2006; Lin et al. 2018). Therefore, when the summer North Atlantic Oscillation (SNAO) pattern shifts eastward with the southern center covering the Mediterranean region, it can excite a wave train pattern to propagate eastward and impact the East Asian summer climate (Sun, Wang, and Yuan 2008; Yulan and Sun 2009; Sun and Wang 2012). Sun and Ming (2018) further found that such an SNAO-related zonal teleconnection pattern can modulate the impact of some factors on the East Asian summer climate. Because the NAO generally indicates the meridional dipole pattern over the North Atlantic region, the SNAO-related zonal teleconnection pattern over the Eurasian Continent is named the Mediterranean–northern Eurasian (MnE) pattern. This zonal teleconnection pattern propagates northeastward from the Mediterranean region along a large circular pathway to northern Eurasia and then southeastward to East Asia (e.g. Sun, Wang, and Yuan 2008; Sun and Wang 2012; Sun et al. 2018). Therefore, to better understand the summer climate variability over East Asia, the combined impact of the PJ and SNAO-related MnE patterns on the East Asian summer atmospheric circulation and SAT are explored.

2. Data and methods

The datasets used here are as follows: (1) the atmospheric data are derived from the Japanese 55-year reanalysis (JRA-55) (Kobayashi et al. 2015), which has a horizontal resolution of $1.25^\circ \times 1.25^\circ$; (2) the SAT data are obtained from the Climate Research Unit TS4 dataset (CRU) (Harris et al. 2014), gridded at a $0.5^\circ \times 0.5^\circ$ resolution. The analysis period is 1958–2016.

The PJ index is defined based on previous studies (Wakabayashi and Kawamura 2004; Kawamura and Ogasawara 2006) as the difference in the 850-hPa geopotential height anomalies between two grid points ((40°N, 150°E) and (25°N, 125°E)) during summer. In addition, the SLP over the Mediterranean region (30°–50°N, 0°–30°E) is referred to as an index to describe the MnE variability, based on previous studies (Sun, Wang, and Yuan 2008; Sun and Wang 2012).

3. Individual influences of the PJ and MnE patterns on East Asian summer SAT

As shown in Figure 1, the PJ and MnE indices show strong interannual variability. During the period 1958–2016, the correlation coefficient between these two indices is low, with a value of $-0.08$. This result indicates that the PJ pattern and MnE pattern are orthogonal to each other and exert independent influence on East Asian summer SAT variability.

Figure 2 shows the atmospheric circulation pattern regressed against the PJ and MnE index, respectively. As shown in Figure 2(a–c), according to the positive PJ pattern, there is a meridional tripole pattern along the East Asian coast, with two significant negative centers over low and high latitudes and a positive center over

![Figure 1](image_url)

Figure 1. Normalized time series of the PJ and MnE indices during summer over the period 1958–2016. Solid lines indicate the +0.5/−0.5 standard deviations.
midlatitudes. The tripole pattern exhibits a quasi-barotropic structure, with a slight northward tilt with height (Yasunaka and Hanawa 2006). Positive/negative geopotential heights are generally related to sunny/cloudy weather, increasing/decreasing insolation at the ground (Figure 3(a)), and consequently favor local warming/cooling of SAT over East Asia, respectively (Kubota, Kosaka, and Xie 2016; Sun, Wang, and Yuan 2011). In addition, the atmospheric dynamics can also change the SAT. Generally, a cyclone/anticyclone favors/prohibits cold-air activity, and therefore the anomalous cyclones/anticyclones in Figure 2 are related to the cold/warm regions in Figure 3. Therefore, both the radiation and dynamics associated with the positive PJ pattern result in a significant warming over Northeast China and Japan, and a cooling over northern East Asia (Figure 3(c)). Such anomalous atmospheric and SAT distributions are consistent with those in previous studies (Nitta 1987; Wakabayashi and Kawamura 2004; Huang 2004).

The MnE-related atmospheric circulations are displayed in Figure 2(d–f). There is a wave train pattern along the large circular pathway over the mid-to-high latitudes of the Eurasian continent. The wave activity flux indicates that such a wave train pattern propagating eastward from the Mediterranean region to East Asia (figure not shown) results in significant negative geopotential height anomalies over central East Asia and positive geopotential height anomalies over northern Eurasia along the coasts of the Kara Sea and Laptev Sea. Influenced by such atmospheric circulations, the radiation flux anomalies show two large significant centers (Figure 3(b)): the positive center is over northern Eurasia under the anomalous positive geopotential height, and the negative center is observed over central East Asia under the anomalous negative geopotential height, which is similar to the SAT pattern (Figure 3(d)). However, the MnE-related significant SAT region over central East Asia (Figure 3(d)) is larger than its related significant radiation flux region (Figure 3(b)), extending more southwestward to northern China and Mongolia (Figure 3(d)). The dynamical process of the MnE-related atmosphere circulation could play an important role in the formation of such an SAT pattern. The anomalous cyclone over central East Asia brings cold air from high latitudes, therefore favoring the cold-air activity and contributing to the cooling over central East Asia, including northern China and Mongolia. In addition, previous studies
have suggested that the upper-level westerly jet plays an important role in the local SAT variability. The easterly anomalies over northern Asia (around 60°N) weaken the polar westerly jet (Figure 2(d–f)), also favoring the southward invasion of cold air from high latitudes. Therefore, although the significant radiation flux anomalies are located mainly over Northeast China, the atmospheric dynamics makes the cold air invade northern China and Mongolia, resulting in a significant cold zonal belt over central East Asia. Such atmospheric and SAT patterns are also consistent with those in previous studies (Yuan and Sun 2009; Sun and Wang 2012; Sun et al. 2018).

The variabilities in the PJ pattern and MnE pattern are independent of each other, which is reflected by the low correlation coefficient between the two indices. The spatial distribution of the atmospheric circulation anomalies related to the PJ and MnE patterns shows substantial differences over the Eurasian region (Figure 2). However, these two pattern-related atmospheric circulation and SAT anomalies overlap over central and northern East Asia. Therefore, it is natural to ask what the impact is of the two-pattern combination on atmospheric circulation and SAT over East Asia. We address this question in the following section.

4. Combined impact of the PJ pattern and MnE on East Asian summer SAT

To investigate the combined effect of the PJ pattern and MnE pattern, depending on their different phases, the analyzed years are categorized into four groups (Table 1) based on criteria with indices greater/less than +0.5/−0.5 standard deviations. Because the composite anomalies of the atmospheric circulation and SAT in +PJ/+MnE (+PJ/−MnE) years are similar to those in −PJ/−MnE (−PJ/+MnE) years, except with opposite sign, the composite differences between the +PJ/+MnE and −PJ/−MnE (+PJ/−MnE and −PJ/+MnE, respectively) are displayed in the following section to reflect the in-phase (out-of-phase) impact of the combination of the PJ and MnE patterns.

Figure 4 shows the composite difference in the atmospheric circulations during the in-phase and out-of-phase PJ-MnE years, respectively. During the in-phase years (Figure 4(a–c)), the positive-phase PJ and MnE patterns are still over the Eurasian continent and western North Pacific, showing a barotropic structure. However, compared to the individual positive-phase PJ and MnE patterns in Figure 2, the larger differences in the atmospheric circulations are over central to northern East Asia. The positive-phase MnE pattern can result in a significant negative
geopotential height anomaly over central East Asia between 40°N and 60°N (Figure 2(d–f)). However, the positive-phase PJ pattern can result in a significant positive geopotential height anomaly over central East Asia between 35°N and 50°N and a negative geopotential height anomaly over northern East Asia north of 60°N (Figure 2(a–c)). Therefore, during the in-phase PJ-MnE years, the destructive superposition of the opposite-sign height anomalies related to the PJ and MnE results in a weaker positive geopotential height anomaly over central East Asia (Figure 4(a–c)). Also, the weak geopotential height over central East Asia during the in-phase PJ-MnE years is related to the weak warm SAT anomaly over the region (Figure 5(a)). In addition, the MnE-related negative geopotential height anomaly over central East Asia can induce the PJ-related negative geopotential high anomaly over northern East Asia extending southward; therefore, during the in-phase PJ-MnE years, the negative geopotential height anomaly center over northern East Asia (Figure 4(a–c)) extends further southward than that during anomalous PJ years (Figure 2(a–c)). Such anomalous atmospheric circulation results in a southward-extended cold SAT center over northern East Asia (Figure 5(a)) compared to that during anomalous PJ years (Figure 3(c)). Therefore, during the in-phase PJ-MnE years, there is a weak SAT signal over central East Asia and an extended significant SAT signal over northern East Asia.

Figure 4(d–f) show the composite difference in the atmospheric circulation during the out-of-phase PJ-MnE years. Compared to the individual PJ and MnE years, the large differences in the atmospheric circulations are also located over central to northern East Asia. First, the negative-phase MnE-related positive geopotential height anomalies overlap with the positive-phase PJ-

### Table 1. List of +PJ/+MnE, +PJ/−MnE, −PJ/+MnE, and −PJ/−MnE years over the period 1958–2016.

|        | +PJ     | −PJ     |
|--------|---------|---------|
| MnE    | 1961 1978 1981 1982 1990 2004 2016 | 1964 1969 1971 1980 1992 1997 2003 2013 |
| −MnE   | 1960 1966 1968 1977 1994 1999 2000 2001 2002 2011 | 1958 1963 1965 1995 1998 2010 2014 |

![Composite differences in the geopotential height (units: gpm) and wind (vectors; units: m s$^{-1}$) at (a) 850 hPa, (b) 500 hPa, and (c) 200 hPa between the +PJ/+MnE and −PJ/−MnE years during summer over the period 1958–2016. (d–f) As in (a–c) but between the +PJ/−MnE and +PJ/+MnE years. The dotted areas are geopotential height anomalies significant at the 95% confidence level. Arrows are the wind anomalies significant at the 95% confidence level.]
related positive geopotential height anomalies over central East Asia. The constructive overlap of the geopotential heights with the same sign results in significant positive geopotential height anomalies over central East Asia. Second, the negative geopotential height anomalies along the coast of the Kara Sea and Laptev Sea associated with the negative MnE pattern can induce the westward extension of the positive-phase PJ-related negative geopotential height anomalies over northern East Asia, resulting in a negative zonal belt over northern Asia. Therefore, during out-of-phase PJ-MnE years, the SAT anomalies show a warm zonal belt over central East Asia and a negative zonal belt over northern Asia (Figure 5(b)).

The analysis indicates that the central East Asia SAT is sensitive to the combination of the PJ and MnE patterns. The in-phase (out-of-phase) combination of the two patterns can weaken (strengthen) SAT anomalies over this region. Therefore, to quantitively explore the combined impact of the PJ and MnE patterns on East Asian SATs, the central East Asian SAT is selected. The central East Asian SAT (CEA-SAT) index is defined as the SAT averaged within (40°–50°N, 110°–150°E).

Figure 5. Composite differences in the SAT (units: °C) (a) between the +PJ/+MnE and −PJ/−MnE years and (b) between the +PJ/−MnE and −PJ/+MnE years during summer over the period 1958–2016. The dotted areas are significant at the 95% confidence level.

Figure 6(a,b) are scatterplots of the PJ index and MnE index versus the CEA-SAT index during 1958–2016. The results suggest a positive correlation between the PJ pattern and central East Asian SAT and a negative correlation between the MnE pattern and central East Asian SAT, with correlation coefficients of 0.36 and −0.35, respectively, which are both significant at the 99% confidence level. However, the high correlations of the PJ and MnE patterns with CEA-SAT are mainly due to their covariability during the out-of-phase PJ-
MnE years. As shown in Figure 6(c,d), during the years when the PJ index has the opposite sign to the MnE index, the correlation coefficient between the PJ and CEA-SAT indices reaches 0.58, and the correlation coefficient between the MnE and CEA-SAT indices reaches −0.66; both are significant at the 99% confidence level.

In contrast, during in-phase PJ-MnE years (Figure 6(e,f)), the correlations of the PJ and MnE patterns with CEA-SAT become weak, with values of 0.09 and 0.00, respectively. The analysis of the scatterplots further implies the importance of the PJ-MnE combined impact on East Asian SAT variations.

**Figure 6.** Scatterplots of the CEA-SAT versus the (a) PJ and (b) MnE indices during summer over the period 1958–2016. (c, d) as in (a, b) but for out-of-phase PJ-MnE years, respectively. (e, f) as in (a, b) but for in-phase PJ-MnE years, respectively.
5. Summary

The PJ pattern is the dominant mode over East Asia and has a profound and direct impact on the East Asian summer climate (e.g. Nitta 1987; Huang and Sun 1992; Huang 2004; Yasunaka and Hanawa 2006; Kosaka et al. 2013). In addition, the PJ pattern also serves as a link to connect the high predictability of the tropical system with the East Asian climate, consequently contributing to East Asian summer climate prediction (e.g. Huang et al. 2004; Wang and Fan 2009; Xie et al. 2016). Therefore, the PJ pattern is important for East Asian summer climate variability and prediction. On the other hand, an anomalous PJ pattern does not always result in an anomalous summer climate over East Asia, possibly because of the balancing effect of other factors on the East Asian summer climate. Therefore, in this study, the combined effect of the PJ pattern and MnE pattern on East Asian atmospheric circulation and SAT in summer is analyzed.

The positive-phase PJ pattern shows a meridional wave train pattern, with positive (negative) geopotential height anomalies over central (northern) East Asia, which generally leads to a warm center over central East Asia and a cold center over northern East Asia. The positive-phase MnE pattern shows a zonal wave train over the Eurasian continent, with positive (negative) geopotential height anomalies over central East Asia.

Figure 7. Scatterplots of the CEA-SAT versus the (a) PJ and (b) MnE indices during summers in out-of-phase PJ-MnE years over the period 1901–2010 using ERA-20C SLP and CRU SAT data. (c, d) as in (a, b) but for in-phase PJ-MnE years, respectively.
Therefore, during the in-phase PJ-MnE years, the MnE-related negative geopotential height anomalies can weaken the PJ-related positive geopotential height anomalies over central East Asia and induce the southward extension of PJ-related negative geopotential height anomalies over northern East Asia. Such atmospheric anomalies favor a weak SAT signal over central East Asia and a significant southward extension of the SAT signal over northern East Asia during in-phase PJ-MnE years. On the other hand, during out-of-phase PJ-MnE years, the same sign for the geopotential height anomalies associated with the PJ and MnE patterns can result in a significant dipole in the geopotential height anomaly zonal belt over central East Asia and northern Asia. Consequently, during the out-of-phase PJ-MnE years, there are opposite and significant SAT anomaly zonal belts over central East Asia and northern Asia. The atmospheric patterns generally have interannual and decadal variability, the results in this study mainly reflect the interannual variability, because the analysis on the nine-year high-pass-filtered data obtains similar results (figure not shown).

To confirm the robustness of the combined effect of the PJ and MnE patterns on East Asian atmospheric circulation and SAT in summer, the ERA-20C (Poli et al. 2016) and CRU SAT data over the period 1901–2010 are used. The long-term data analysis further confirms that the combination of the PJ and MnE during different phase years can result in different anomalous SAT over East Asia (Figure 7), which is highly consistent with the results obtained from the past half century. The analysis in this study indicates that the combined effect of the PJ and MnE patterns is necessary to better understand and predict East Asian summer atmospheric circulation and SAT variability.

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