Close relationship between the East Asian westerly jet and Russian far East surface air temperature in summer

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\begin{abstract}
The interannual variability of the east asian upper-tropospheric westerly jet (EAJ) in summer is characterized by the meridional displacement of its axis, or a seesaw pattern of zonal wind anomalies between the northern and southern flanks of the EAJ. This study reveals a close relationship between the surface air temperature in the russian far east and the northern flank of the EAJ. Related to a warmer surface in the russian far east, the westerly decelerates in the northern flank of the EAJ. The relationship can be explained by a positive feedback mechanism between the surface air temperature in the russian far east and the overhead circulation: the anticyclonic circulation anomaly related to a weakened westerly in the northern flank of the EAJ induces surface warming in the russian far east and the warmer surface can in turn act as a heat source and induces a local anticyclonic circulation anomaly in the upper troposphere, therefore decelerating the westerly in the northern flank of the EAJ. The result implies that a better description of the summer surface condition in the russian far east may benefit seasonal forecasts of the EAJ and, subsequently, east asian summer climate.
\end{abstract}

1. Introduction

The interannual variation of the East Asian upper-tropospheric westerly Jet (EAJ) in summer is mainly characterized by a meridional displacement of upper-tropospheric zonal wind anomalies (e.g. Lu 2004; Lin and Lu 2005), which significantly affects precipitation and temperature in East Asia (Lau, Kim, and Yang 2000; Wang et al. 2013). The meridional displacement index is generally depicted by the difference in upper-tropospheric zonal winds between the northern and northern flanks of the EAJ. The northern flank of the EAJ is one of the two components of, and contributes largely to, the interannual variation of the EAJ. Remarkable interannual variability has been shown in the northern flank of the EAJ, which is even larger than in the southern flank (Li and Lin 2015), implying substantial impacts on the meridional displacement of the EAJ.

Tropical air–sea interaction plays an important role in the meridional displacement of the EAJ (e.g. Lu 2005; Lin and Lu 2009; Lin 2010; Qu and Huang 2012). Through analyzing the predictability of the EAJ, Li and Lin (2015) found that significant responses to these tropical signals are detected mainly over the southern flank of the EAJ. In contrast, the interannual variation of the northern flank of the EAJ shows a relatively weak teleconnection with tropical air–sea interactions and has a poor seasonal forecast skill. The correlation coefficient between the observed and multi-model-ensembles forecast northern flank of the EAJ during 1960–2005 is only 0.06. Until now, the factors responsible for the interannual variation of the northern flank of the EAJ have remained unclear.

The present study reveals a close relationship between the northern, but not the southern, flank of the EAJ and surface air temperature in the Russian Far
East in summer. Moreover, the associated circulation changes and possible mechanism are also explored. This work is potentially helpful in better understanding the interannual variations and predictability of the meridional displacement of the EAJ and, consequently, East Asian summer climate.

2. Data, indices, and model

This study focuses on the boreal summer season (June–August). The monthly atmospheric circulation and surface air temperature data from 1958 to 2015 are from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis dataset (Kalnay 1996).

The meridional displacement of the EAJ index (EAJ) is defined as the difference in zonal wind anomalies at 200hPa averaged between the northern flank region (40°–50°N, 120°–150°E) and southern flank region (30°–40°N, 120°–150°E) of the EAJ, following Lu (2004) and Lin and Lu (2005). A positive (negative) EAJ indicates a northward (southward) displacement of the EAJ. Also used is an EAJ northern flank index (EAJNI), defined as the zonal wind anomalies at 200hPa averaged over the northern flank region (40°–50°N, 120°–150°E). In addition, a surface air temperature index (TSI) over (50°–70°N, 110°–150°E) is calculated to depict the variation of surface air temperature around the Russian Far East. It is found to closely connect with the northern flank of the EAJ in this study.

To verify the effect of regional surface air temperature on circulation in the upper troposphere, a linear baroclinic model (LBM) is used (Watanabe and Kimoto 2000; Watanabe and Kimoto 2001). The LBM consists of the primitive equations linearized about the climatology, which is generated from the NCEP–NCAR dataset averaged over 1958–97. The model has a horizontal resolution of T42 and 20 vertical levels using the sigma coordinate system. The level of 200hPa in the pressure coordinate system amounts to the level of 0.22 in the sigma coordinate system. Since responses of the circulation to heat forcing will be stable after approximately 15 days, the outputs from day 16 to day 20 are averaged as the steady response to the prescribed diabatic heating forcing.

3. Results

Figure 1 shows the standardized time series of the EAJNI and EAJ from 1958 to 2015. The EAJNI demonstrates strong interannual variability, its interannual standard deviation being 2.49 m s⁻¹. In addition, the northern and southern flanks contribute similarly to the EAJI; the correlation coefficient between the EAJNI and EAJI is 0.75, and the correlation coefficient between the EAJ and zonal winds averaged over the southern flank region (30°–40°N, 120°–150°E) is −0.81.

A close relationship is detected between the interannual variation of the northern flank of the EAJ and the surface air temperature around the Russian Far East (Figure 2(a)), with significant correlation coefficients over the key region (50°–70°N, 110°–150°E). The correlation coefficient between the averaged surface air temperature index over the key region (TSI) (Figure 1) and the EAJNI is −0.51, exceeding the 99% confidence level according to the Student’s t-test. This correlation remains high (−0.48) even after it is detrended, suggesting a robust relationship between them on the interannual time scale. Specifically, associated with an anomalously warm (cold) surface air temperature in the Russian Far East, the upper-tropospheric westerly wind will be weakened (enhanced) over the northern flank of the EAJ. In addition, it is noted that the surface air temperature anomalies related to the EAJNI are mainly confined in the mid–high-latitude region around the Russian Far East, with no signal in the tropical region, consistent with the low predictability of the northern flank of the EAJ in current dynamical seasonal predictions based on atmosphere–ocean coupled models (Li and Lin 2015).

The meridional displacement of the EAJ also varies closely with the anomalous surface temperature around the Russian Far East (Figure 2(b)). The correlation coefficient between the TSI and EAJNI reaches −0.48. Nevertheless, this value drops to −0.16 after removing the effect of the northern flank via subtracting linear components regressed upon the EAJNI (Figure 2(c)). This suggests that the close relationship between the meridional displacement of the EAJ and
Surface air temperature around the Russian Far East arises from the contribution of the northern flank of the EAJ. Besides, the meridional displacement of the EAJ shows good connections with the tropical surface temperature (Figure 2(b) and (c)), which is probably related to the southern flank as the tropical signal remains after removing the impact of the EAJNI (Figure 2(c)). The result is consistent with the conclusion of Li and Lin (2015). The air–sea interactions in the tropics can modulate the southern flank of the EAJ, probably via affecting the convection around the subtropical western North Pacific (Lin 2010; Li and Lin 2015).

The circulation anomalies in the upper troposphere related to the TSI (Figure 3(a)) further reveal its close relationship with the northern flank of the EAJ. Regressed onto the TSI, an anomalous anticyclonic circulation at 200 hPa is shown overhead in the Russian Far East. In the northern flank of the EAJ, a remarkable easterly anomaly is associated with this anticyclone, consistent with its negative correlation with the Russian Far East surface air temperature. Also noticeable is a westerly anomaly in the tropical regions and a cyclonic circulation anomaly over East Asia, which arises largely from the contribution of the warming trend in the Russian Far East in recent decades as they are significantly suppressed after removing the linear trend in the TSI (Figure 3(b)).
The upper-tropospheric anticyclone around the Russian Far East implies a crucial role in the variation of the surface air temperature underneath. It varies in association with an anomalous easterly anomaly in the northern flank of the EAJ, which would induce descending motion in the troposphere (figure not shown), increase incoming radiation, and then warm the surface air temperature in the Russian Far East.

On the other hand, surface air temperature, which is perceived as one of the key elements of surface or near-surface climate, could affect the circulation above through modulating the meridional gradient of temperature (e.g. Stone 1978; Lindzen, Farrell, and Tung 1980; Gutowski 1985). In view of the difficulty in diagnosing the causality between surface air temperature and circulation through observational analyses, a numerical experiment with a prescribed surface heat forcing in the LBM is thus performed to investigate the role played by surface air temperature in the Russian Far East.

Figure 4(a) and (b) show the horizontal distribution and vertical profile of the heat source prescribed in the LBM. The maximum heat source is set on the surface at the sigma level of 0.995 with maxima of 2 K d$^{-1}$ centered at (60°N, 130°E) (Figure 4(a)). The intensity of the heat source decreases with the height and closes to zero at the upper level of the troposphere (Figure 4(b)).

In response to the surface warming around the Russian Far East, a remarkable anticyclonic circulation anomaly is found overhead in the upper troposphere north of the EAJ axis at approximately 40°N (Figure 4(c)), reproducing well the related circulation in observations (Figure 3(a) and (b)). The southern component of the anticyclone, i.e. the easterly anomaly, overlaps the northern flank of the EAJ. The result supports that the surface air temperature in the Russian Far East can exert influence on the northern flank of the EAJ, not just the result of the circulation. Moreover, the easterly wind anomaly in the northern flank of the EAJ in response to a warmer Russian Far East surface air temperature is consistent with the observational negative correlation between them, suggesting positive feedback of the latter to the former.

4. Conclusion

In this study, we focus on the summer interannual variation of the northern flank of the EAJ and investigate its relationship with underlying surface air temperature. A close relationship between the northern flank of the EAJ and Russian Far East surface air temperature is detected. The correlation coefficient between the EAJNI and TSI during 1958–2015 reaches −0.51. The close relationship dominates the teleconnections of the meridional displacement of the EAJ with the mid–high-latitude surface condition, and no clear correlation exists after removing the contribution of the northern flank of the EAJ.

The coupling of the northern flank of the EAJ with a warmer surface air temperature around the Russian Far East is associated with an anticyclonic circulation anomaly overhead in the Russian Far East. The anticyclonic circulation anomaly induces surface warming in the Russian Far
East. On the other hand, the surface warming in the Russian Far East in turn acts as a heat source and decelerates the westerly in the northern flank of the EAJ, based on the simulation results of a simple model. It is consistent with the observational negative correlation, suggesting positive feedback of surface air warming in the Russian Far East to circulations overhead.

Li and Lin (2015) revealed that the prediction skill of upper-tropospheric zonal winds is confined to the southern flank of the EAJ. In this study, we find a close relationship between Russian Far East surface air temperature and the westerly in the northern flank of the EAJ. This close relationship suggests further description of the surface condition and air–land interactions around the Russian Far East has the potential to improve seasonal forecasts of the northern flank and meridional displacement of the EAJ and, consequently, summer climate in East Asia.

Disclosure statement

No potential conflict of interest was reported by the authors.

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