Atmospheric and Oceanic Science Letters

ISSN: 1674-2834 (Print) 2376-6123 (Online) Journal homepage: http://www.tandfonline.com/loi/taos20

A southward withdrawal of the northern edge of the East Asian summer monsoon around the early 1990s

Xiao-Cui ZHU, Yuan-Yuan GUO, Hai-Yan ZHANG, Xiu-Zhen LI, Rui-Dan CHEN & Zhi-Ping WEN

ATMOSPHERIC AND OCEANIC SCIENCE LETTERS, 2018
VOL. 11, NO. 2, 136–142
https://doi.org/10.1080/16742834.2018.1410058

Taylor & Francis
Taylor & Francis Group

A southward withdrawal of the northern edge of the East Asian summer monsoon around the early 1990s

ZHU Xiao-Cui[a], GUO Yuan-Yuan[a], ZHANG Hai-Yan[a,b], LI Xiu-Zhen[a,c], CHEN Rui-Dan[a,c] and WEN Zhi-Ping[a,c,d]

[a]Center for Monsoon and Environment Research, School of Atmospheric Sciences, Sun Yat-sen University, Guangzhou, China; [b]South China Sea Marine Forecasting Center of State Oceanic Administration, Guangzhou, China; [c]Jiangsu Collaborative Innovation Center for Climate Change, Guangzhou, China; [d]Institute of Atmospheric Sciences, Fudan University, Shanghai, China

ABSTRACT

The northern edge of the East Asian summer monsoon (EASM) is identified using the pentad total column water vapor obtained from ERA-Interim reanalysis data during 1979–2015. Empirical orthogonal function analysis is applied to study the meridional displacement of the northern edge of the EASM during the study period, and the results show an interdecadal southward shift around 1993/1994 and an indistinct northward displacement after 2007/2008. To focus on the interdecadal change around 1993/1994, composite analysis using the difference between 1979–1993 and 1994–2007 is employed. Through examination of the differences between these two periods, a significant anticyclonic anomaly is found over Mongolia, suggesting a pronounced interdecadal weakening of the Mongolian low during 1994–2007. Thus, northward advancement of the EASM may have been prevented by the anomalous northerly flow to the east of the weakened Mongolian low after 1993. Further study shows that the interdecadal weakening of the Mongolian low might be attributable to the meridional inhomogeneity of surface warming over the northern part of East Asia. Previous studies suggest that such meridional inhomogeneity would lead to a reduction in local atmospheric baroclinicity, and thus the suppression of extratropical cyclone activity over Mongolia, resulting in a southward withdrawal of the northern edge of the EASM on the interdecadal timescale.

摘要

利用1979–2015的ERA-Interim的逐候可降水量资料，定义了东亚夏季风的北边界位置，并应用EOF分析方法研究东亚夏季风边界位置变化的时空分布特征。研究结果显示，第一模态代表东亚夏季风北边界的经向位置变动，其时间系数表现出显著的年代际变化特征。在1993/94年之后东亚夏季风北边界发生了年代际南移，而在2007/08后趋向北移。对1979–1993和1994–2007两个时段的气象要素场进行合成分析发现，其低层环流的年代际差值场在蒙古地区为一显著的反气旋环流异常，表明1993/94年之后蒙古低压年代际减弱，此异常反气旋性环流东侧的异常北风则不利于东亚夏季风的北推，可能导致季风北界位置偏南。进一步分析表明，东亚北部的地表不均匀性增温可能是造成蒙古低压的年代际减弱的原因。

ARTICLE HISTORY
Received 15 September 2017
Revised 27 September 2017
Accepted 28 September 2017

KEYWORDS
East Asian summer monsoon; interdecadal change; Mongolian extratropical cyclone; Mongolian low; surface warming

关键词
东亚夏季风; 年代际变化; 蒙古副热带气旋; 蒙古低压; 表面增温

1. Introduction

The northern edge of the East Asian summer monsoon (EASM) is considered to be the northernmost boundary to which this summer monsoon system can advance, and as the transition zone between the monsoon and non-monsoon area. Its south–north displacement exerts direct influences on the weather and climate change over East Asia, especially for the edge region where the ecological system is fragile (Xu and Qian 2003; Lin and Qian 2012), as manifested, for example, by the occurrence of extreme drought in Northwest China, rainstorms in eastern Northwest China (Tang, Sun, and Qian 2007), and sand-dust in northern China (Sun, Tang, and Li 2008). Hence, the variability of the northern edge of the EASM is a topic of great scientific importance and practical significance, considering its prominent socioeconomic impacts throughout China (Li et al. 2013).

Substantial efforts have been devoted to investigating the characteristics of the northern edge of the EASM, including its northward shift, withdrawal, and influence on the surrounding climate variability (Tang 1983; Wang et al. 1999; Hu and Qian 2007; Li and Han 2008). According to previous research, the northern edge of the EASM exhibits significant interannual and interdecadal variations (Wu, Liu, and Xie 2005; Jiang et al. 2006;

CONTACT WEN Zhi-Ping eeswzp@mail.sysu.edu.cn

Qian et al. 2007; Sun, Tang, and Li 2008). For instance, on the interannual timescale, the meridional displacement of the northern edge of the EASM varies from year to year. On the interdecadal timescale, many studies have focused on the interdecadal shift of the northern edge of the EASM in the late 1970s and its relationship with East Asian rainfall (Jiang et al. 2006; Tang, Qian, and Liang 2006; Fu and Liu 2007; Jiang et al. 2008; Li and Han 2008), while much less attention has been paid to its causes, with the notable exception of Wang and Li (2011) who proposed that the changes in surface sensible heat flux over the arid region of Northwest China may influence the northern boundary of the EASM.

It is well known that the EASM systems have undergone remarkable interdecadal changes, not only in the late 1970s but also the early 1990s (Kwon, Jhun, and Ha 2007; Lv, Zhang, and Chen 2011; Zhu, Li, and He 2014; Zhang et al. 2016; Zhu and Li 2017). Most previous studies suggest that the northern edge of the EASM witnessed a significant interdecadal southward movement around the late 1970s. However, whether the northern edge of the EASM also experienced an interdecadal change in the early 1990s remains unclear. Hence, the objective of the present study is to answer the following questions: Was there an interdecadal change in the northern edge of the EASM around the early 1990s? And if so, what mechanism was responsible for this interdecadal change?

The paper is organized as follows: The data-set and methodology are briefly described in Section 2. The variability of the northern edge of the EASM based on empirical orthogonal function (EOF) analysis is investigated in Section 3. The possible mechanism responsible for the interdecadal changes in the northern edge of the EASM is discussed in Section 4. And finally, a summary of the study's key findings is provided in Section 5.

2. Data-set and methodology

2.1. Data-set

A global six-hourly data-set derived from ERA-Interim at a spatial resolution of 1° × 1°, including the total column water vapor (TCWV), specific humidity, horizontal wind, geopotential height, surface pressure, and skin temperature, is used in this study (Dee et al. 2011). In addition, daily rain gauge data from 756 meteorological stations, provided by the Chinese Meteorological Data Service Network, are also applied, after interpolation onto a 1° × 1° grid. The data period is 1979–2015, and all the six-hourly and daily data are converted into pentad-mean data.

2.2. Methodology

The vertically integrated meridional water vapor flux (Q_v) is calculated as

$$Q_v = \frac{1}{g}\int_{300}^{P_s} qv\,\mathrm{d}p$$

where g is gravitational acceleration, P_s is surface pressure, q is specific humidity, and v is meridional wind.

EOF analysis and composite analysis are used in this study. The significance of the results is evaluated via the two-sided Student's t-test at the 0.1 significance level.

3. Variability of the northern edge of the EASM

3.1. Definition of the northern edge of the EASM

It is well known that the activity of the EASM is characterized by remarkable enhancements in precipitation and southerly wind. Hence, related parameters, such as precipitation, water vapor transport, and the wind field, have been applied to study the variability of the northern edge of the EASM in many previous studies (Wang et al. 1999; Tang, Qian, and Liang 2006; Li and Han 2008). For example, Qian et al. (2007) determined the northern edge of the EASM using the precipitation isocline of 4 mm d^{-1}. Tang, Qian, and Liang (2006) used the vertically integrated meridional water vapor flux (Q_v) equaling 5 kg m^{-1} s^{-1} to measure the northern edge of the EASM by considering that the summer monsoon water transport over East Asia is dominated by meridional transport (Huang et al. 1998; Zhu, He, and Qi 2012). In addition, Jiang et al. (2006) found that the variability of the ridge of the subtropical high ($U_{500\ \mathrm{hPa}}$ = 0 m s^{-1}) was consistent with the northern position of the monsoon front and could partly reveal the northerly advancement of the EASM. The pentad means of these indices are displayed in Figure 1, showing the climatological northward movement of the edge from winter to summer. The variations of these indices are consistent in revealing the northward advancement of the EASM and the time taken to reach the northern boundary both in the western part (Figure 1(a)) and the eastern part (Figure 1(c)). The consistency among these indices is even more obvious when the area mean between 105°E and 135°E is considered (Figure 1(d)). However, the index of the ridge of the subtropical high ($U_{500\ \mathrm{hPa}}$ = 0 m s^{-1}) shows some subtle differences insofar as its position is relatively more southward compared with the other indexes. The northern edge measured by the precipitation and wind is characterized by many small-scale perturbations along the edge (Figure 1), and these indices might suffer from their own weaknesses in identifying the large-scale variation of the northern edge of the EASM.

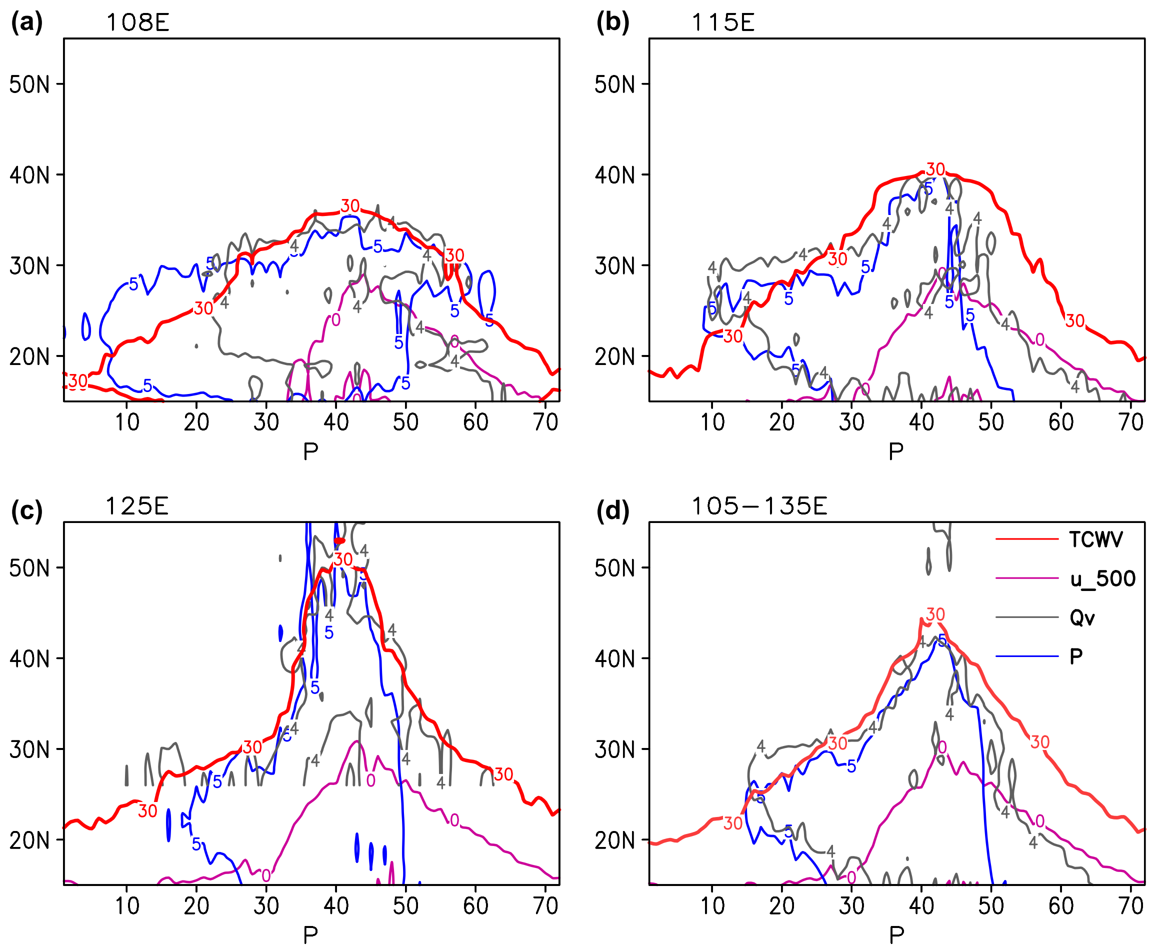

Figure 1. Climatological annual cycle of the pentad-mean total column water vapor (TCWV, red line), 500-hPa zonal wind (magenta line), meridional water vapor flux (Q_v, blue line), and precipitation (gray line), at (a) 108°E, (b) 115°E, (c) 125°E, and (d) the average over 105°–135°E.

Notes: The red thick curve is the isocline of TCWV = 30 mm. The magenta line represents the zonal wind at 500 hPa where $U_{500} = 0$ m s^{-1} (Jiang et al. 2006). The blue line represents the vertically integrated $Q_v = 5$ kg m^{-1} s^{-1} (Tang, Qian, and Liang 2006). The gray line indicates the precipitation of 4 mm d^{-1} (Qian et al. 2007).

Compared with these variables, TCWV has been suggested as a better proxy to measure the distributions of both moisture and rainfall on a broader spatial scale (Tang et al. 2010); plus, it is a relatively steady variable. Furthermore, Zeng and Lu (2004) pointed out that TCWV could largely reflect the physical nature of the EASM. Therefore, in this paper, TCWV is used to identify the northern edge of the EASM. In Figure 1, we note that the TCWV equal to 30 mm is consistent with the above indices in describing the climatological northward movement of the EASM over both the western and eastern parts of East Asia. Other TCWV criteria apart from 30 mm were also examined, and it was found that 30 mm is better for identifying the variability of the northern edge of the EASM (figure not shown). Therefore, the criterion of TCWV = 30 mm is proposed to identify the northern edge of the EASM.

Accordingly, the northern edge of the EASM is defined as the latitude where the pentad TCWV equals 30 mm and lasts for at least two pentads at each longitude over East Asia (105°–135°E). As shown in Figure 1, compared with other indices, the index defined using TCWV has its own advantages; for instance, the northern edge of the EASM is smoother and some local perturbations are ruled out. Hence, the index defined in this study is more appropriate in portraying the large-scale characteristics of the EASM. Moreover, the latest pentad when the most northern point of the summer monsoon at each longitude over 105°–135°E satisfies the above condition is taken as the arrival time of the northern edge of the EASM for each year.

3.2. Interdecadal variation of the northern edge of the EASM

According to the criterion given above, Figure 2(a) shows the location of the northern edge of the EASM during 1979–2015. The geographical location of the northern edge of the EASM reaches 35°N in North China and 52°N in Northeast China, showing a southwest–northeast tilting

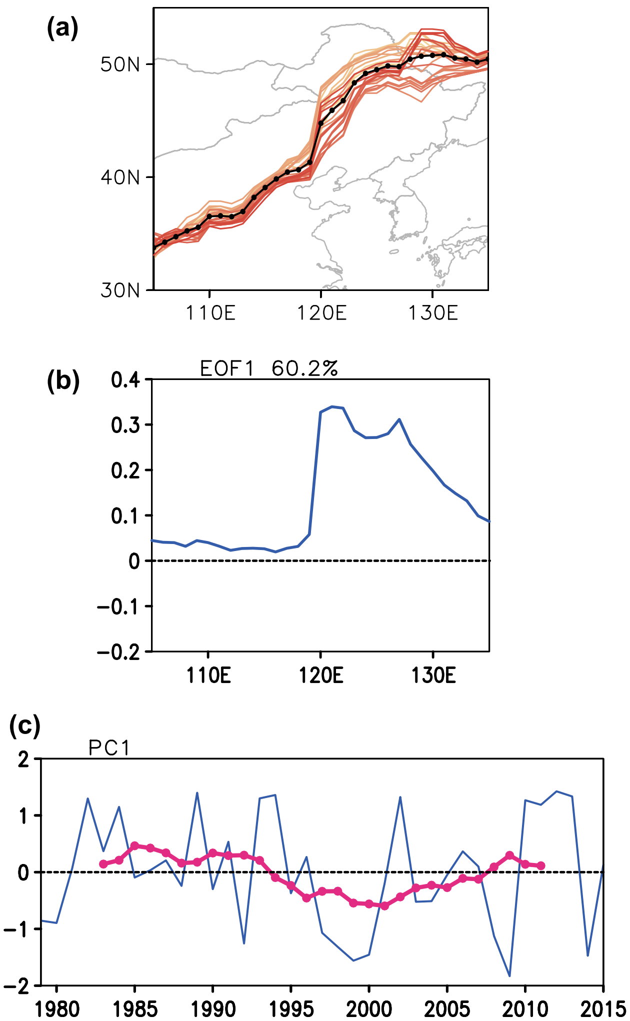

Figure 2. (a) Location of yearly northern edges (orange lines) of the EASM during 1979–2015 and their average position (black line) during the same period. (b) First EOF mode of the location of the northern edge of the EASM, and (c) the corresponding time coefficient from 1979 to 2015.
Note: The red curve in (c) represents the 9-yr running mean of PC1.

structure, which is consistent with the results presented in previous studies (Tao and Chen 1985; Tang, Qian, and Liang 2006). The interannual variation of the northern edge of the EASM is pronounced, especially over Northeast China to the east of 120°E.

To analyze the spatial and temporal characteristics of the northern edge of the EASM, an EOF analysis based on the latitude where the northern edge reaches over East Asia during 1979–2015 is conducted. The abnormal latitude value of the northern edge at each longitude during 1979–2015 is the input to the EOF analysis. The spatial pattern of the first EOF mode (EOF1) and its corresponding time coefficient are displayed in Figure 2(b) and (c). The leading mode accounts for 60.2% of the total variance. In Figure 2(b), the spatial pattern of EOF1 is of the same sign, indicating synchronous south–north displacement of the northern edge in both the eastern and western parts. However, the magnitude to the east of 120°E is much larger than that to the west, suggesting a much larger meridional variability of the northern edge of the EASM over Northeast China, which is consistent with its yearly displacement shown in Figure 2(a). Besides the interannual variation, there is a significant interdecadal variation in the corresponding principal component (PC1) based on the 9-yr running mean of PC1. The PC1 shifts from positive to negative around the early 1990s. Therefore, this mode captures an interdecadal southward shift of the northern edge of the EASM around 1993. Another shift in 2007/2008 is also noted in Figure 2(c). The robustness of these two shifts was also found using 11-yr and 13-yr running windows (figures not shown). In this study, only the interdecadal change around 1993 is discussed in detail.

4. Possible mechanisms responsible for the 1993/1994 shift of the northern edge of the EASM

The above results show that the northern edge of the EASM withdrew southward after 1993, especially over Northeast China. To investigate the possible underlying mechanisms, two periods, 1979–1993 and 1994–2007 (referred to as epoch 1 and epoch 2, respectively), are selected for further investigation. Composite analysis is performed based on the pentads when the monsoon reached the northern edge in each year. Figure 3(a) and (b) show the mean 850-hPa horizontal winds when the monsoon reached the northern edge during 1979–1993 and 1994–2007, respectively. In epoch 1, strong southerly winds are observed to the east of 105°E, which can advance to the north of 50°N. For epoch 2, the southerly winds shift eastward, and strong southerly winds are mainly advected by the western Pacific subtropical high appearing mostly over the western North Pacific to the east of 120°E. The monsoon flow is much weaker over East China. Over northern East Asia, compared with that in epoch 1, the southerly winds withdraw much more southward in epoch 2 between 120°E and 140°E. In the difference field (i.e. the 1994–2007 mean minus the 1979–1993 mean), a significant anticyclonic anomaly appears over the Mongolian region (40°–50°N, 90°–120°E) (Figure 3(c)). This indicates the Mongolian extratropical cyclone weakened during the period 1994–2007. The significant northerly anomaly to the east of the Mongolian extratropical anticyclonic anomaly over Northeast China may have prevented the northward advancement of the EASM, resulting in the interdecadal southward displacement of its northern edge.

By its very nature, the extratropical anticyclonic anomaly over Mongolia is indicative of a lower frequency of extratropical cyclonic activity over Mongolia. As stated

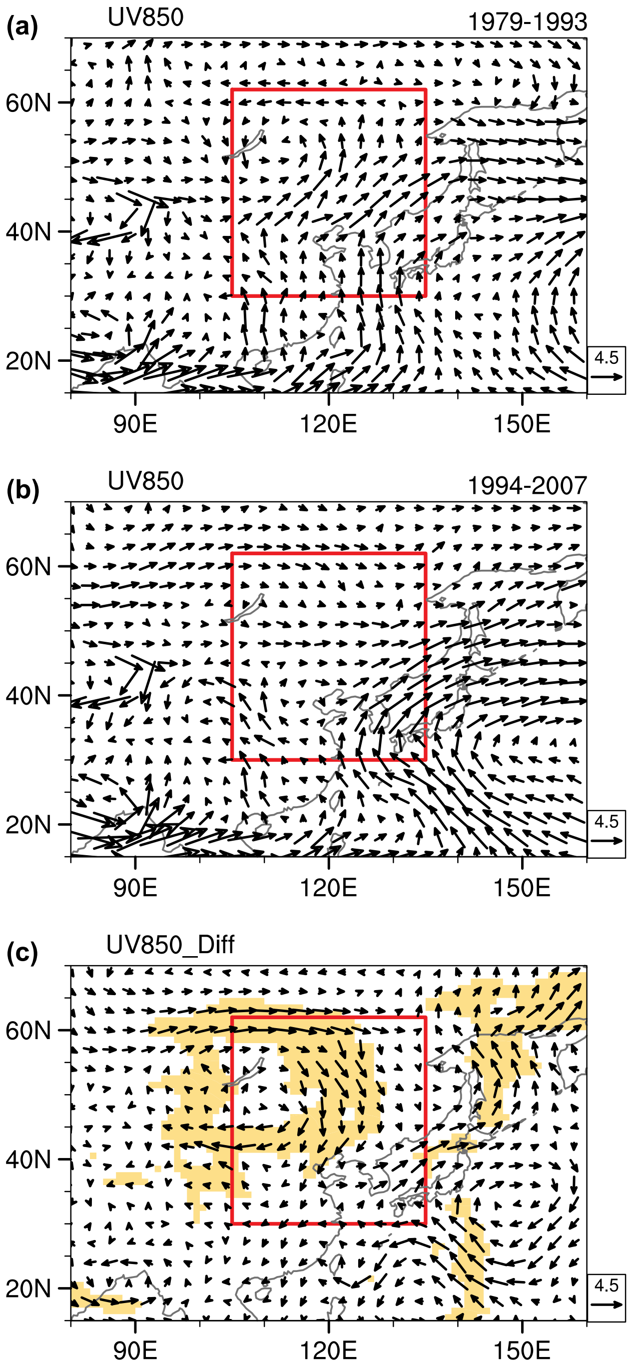

Figure 3. Mean horizontal wind at 850 hPa (vectors; units: m s^{-1}) for the period (a) 1979–1993 and (b) 1994–2007, averaged for all pentads when the monsoon reached the identified northern edge of the EASM in each year, and (c) their difference (1994–2007 minus 1979–1993).

Notes: The shading in (c) denotes differences exceeding the 90% confidence level based on the Student's *t*-test. The area within the red box is the main research area for the northern edge of the EASM.

by Zhang (2017), the accumulative effect of extratropical cyclone activity over Mongolia can be illustrated by the large-scale summertime Mongolian low. Hence, the interdecadal differences in the surface pressure and geopotential height at 850 hPa where the Mongolian low mainly exists are analyzed (Figure 4(a) and (b)). As we can see, there are significant positive anomalies over Mongolia in both the surface pressure and 850-hPa geopotential height. This pronounced interdecadal weakening of the Mongolian low indicates inactive extratropical cyclone activity, and hence weak southerly flow over North and Northeast China during 1994–2007, which is consistent with previous studies (Wu et al. 2010; Zhu et al. 2013; Zhang et al. 2016; Zhang 2017).

The possible causes of the interdecadal weakening of the Mongolian low are also investigated. Surface warming in the Lake Baikal region was proposed by Zhu et al. (2012, 2013) as a possible reason. Our results suggest that East Asia was covered by a large range of significant warming after 1993 (Figure 4(c)). To verify this, the interdecadal difference in the surface temperature between the two epochs is composited (Figure 4(c)). A wide area over the northern part of East Asia experiences a significant warming after 1993, especially to the west of the Lake Baikal area (at about 50°N), with the maximum warming exceeding 3 K. Notably, the amplitude of the surface warming is much smaller to the south over the Inner Mongolia Plateau (~40°N), leading to an obvious south–north contrast in temperature. Such meridional inhomogeneity of the surface warming in the northern part of East Asia may have played an important role in the interdecadal weakening of the Mongolian low, which may in turn have resulted in the interdecadal change in the northern edge of the EASM.

The modulation of the interdecadal weakening of the Mongolian low by the meridional inhomogeneity of the surface warming over East Asia was studied by Zhang (2017). It was proposed that the meridional inhomogeneity of surface warming over East Asia would weaken the vertical wind shear over Mongolia and result in a significant decrease in static stability, thus leading to a weakening of local atmospheric baroclinicity. This is disadvantageous to the occurrence and development of regional synoptic extratropical cyclone activity over Mongolia. The cumulative effect of such a reduced frequency of Mongolian cyclone activity would have been conducive to a weakening of the Mongolian low after 1993/1994. To summarize, the spatially uneven surface warming over East Asia in epoch 2 hindered the Mongolian low through weakening the local atmospheric baroclinicity, thus favoring the withdrawal of the southerly flow over East Asia, which was in tandem with the southward movement of the northern edge of the EASM.

5. Summary

The northern edge of the EASM was defined in this study as the latitude where the TCWV equals 30 mm and lasts

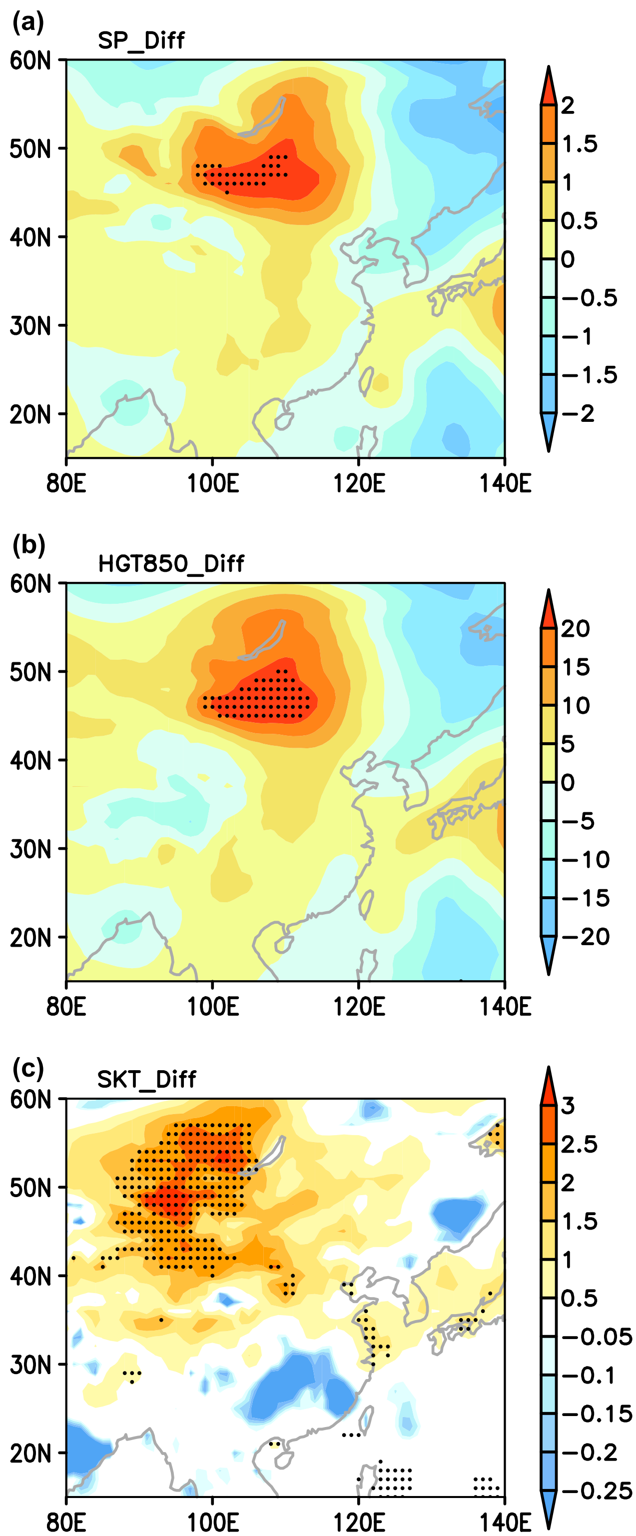

Figure 4. Difference in (a) surface pressure (units: hPa), (b) 850-hPa geopotential height (units: hPa), and (c) skin temperature (units: K) between 1994–2007 and 1979–1993.

Note: The dots represent differences exceeding the 90% confidence level based on the Student's *t*-test.

for at least two pentads. Climatologically, the northern edge is characterized by a southwest–northeast tilting structure. Besides interannual variation, the meridional displacement of the northern edge of the EASM shows strong interdecadal variation during 1979–2015, especially over Northeast China, where the variability is most prominent. Based on EOF analysis, the northern edge of the EASM exhibits a striking interdecadal change around 1993. Specifically, it experienced an obvious southward shift after 1993 and a distinct northward movement after 2007.

The interdecadal variation of the northern edge of the EASM around the early 1990s may be attributable to the anticyclonic anomaly over Mongolia, i.e. a weakening of the Mongolian low. The northerly flow anomaly to the east of the Mongolian anticyclonic anomaly prevented the northward advancement of the EASM, resulting in a southward shift of the edge after 1993/1994. It was found that the meridional inhomogeneity of the surface warming, i.e. increasing temperature to the west of the Lake Baikal area, was more prominent than that over the Inner Mongolian Plateau adjacent to North China. Such inhomogeneous warming would have led to reduced local atmospheric baroclinicity, and thus might have effectively suppressed the extratropical cyclone activity over Mongolia. Accordingly, the southerly monsoon flow would have been hindered after 1993/1994.

Acknowledgement

We thank the anonymous reviewers for their helped comments and suggestions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was jointly supported by National Key Basic Research and Development Projects of China [grant number 2016YFA0600601] and the National Natural Science Foundation of China [grant numbers 41530503, 41405045, and 41605027].

References

Dee, D. P., S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, et al. 2011. "The ERA-interim Reanalysis: Configuration and Performance of the Data Assimilation System." *Quarterly Journal of the Royal Meteorological Society* 137: 553–597. doi:10.1002/qj.828.

Fu, Y. H., and X. F. Liu. 2007. "Interdecadal Fluctuations of the Monsoon's Boundary Zone in the Northern China." *Journal of Nanjing Institute of Meteorology (in Chinese)* 30 (1): 94–100. doi:10.3969/j.issn.1674-7097.2007.01.013.

Hu, H. R., and W. H. Qian. 2007. "Confirmation of the Northern Margin of East Asian Summer Monsoon." *Progress in Natural Science (in Chinese)* 17 (1): 57–65. doi:10.3321/j.issn:1002-008X.2007.01.009.

Huang, R. H., Z. Zhang, G. Huang, and B. H. Ren. 1998. “Characteristics of the Water Vapor Transport in East Asian Monsoon Region and Its Difference from That in South Asian Monsoon Region in Summer.” *Scientia Atmospheric Sinica* 22: 368–379.

Jiang, Z. H., J. H. He, J. P. Li, J. Yang, and J. Wang. 2006. “Northerly Advancement Characteristics of the East Asian Summer Monsoon with Its Interdecadal Variations.” *Journal of Geography* 61 (7): 675–686. doi:10.3321/j.issn:0375-5444.2006.07.001.

Jiang, Z. H., S. Yang, J. He, J. Li, and J. Liang. 2008. “Interdecadal Variations of East Asian Summer Monsoon Northward Propagation and Influences on Summer Precipitation over East China.” *Meteorology & Atmospheric Physics* 100 (1–4): 101–119. doi:10.1007/s00703-008-0298-3.

Kwon, M. H., J. G. Jhun, and K. J. Ha. 2007. “Decadal Change in East Asian Summer Monsoon Circulation in the mid-1990s.” *Geophysical Research Letters* 34 (21): 377–390. doi:10.1029/2007GL031977.

Li, C., and X. Han. 2008. “Relationship of Northern Boundary of East Asian Summer Monsoon and Summer Precipitation in Eastern Part of China.” *Plateau Meteorology (in Chinese)* 27 (2): 325–330.

Li, D. L., P. C. Shao, H. Wang, and L. Chen. 2013. “Advances in Research of the North Boundary Belt of East Asia Subtropical Summer Monsoon in China.” *Plateau Meteorology (in Chinese)* 32 (1): 305–314. doi:10.7522/j.issn.1000-0534.2012.00030.

Lin, X., and W. H. Qian. 2012. “Review of the Global Monsoon and Monsoon Marginal Zones.” *Advances in Earth Science (in Chinese)* 27 (1): 26–34.

Lv, X. Y., X. Z. Zhang, and J. N. Chen. 2011. “The Inter-decadal Variability of North-South Movement of East Asian Summer Monsoon and Its Effect on the Regional Rainfall over China.” *Journal of Tropical Meteorology (in Chinese)* 27 (6): 860–868.

Qian, W. H., X. Lin, Y. F. Zhu, Y. Xu, and J. L. Fu. 2007. “Climatic Regime Shift and Decadal Anomalous Events in China.” *Climatic Change* 84 (2): 167–189. doi:10.1007/s10584-006-9234-z.

Sun, G. W., X. Tang, and J. P. Li. 2008. “Study on the Northern Margin and Sandstorm of Summer Monsoon.” *Plateau Meteorology (in Chinese)* 27 (5): 1088–1093.

Tang, M. 1983. “The Advance and Retreat of the 1979 Summer Monsoon Onset over East China.” In *Proceedings of the Symposium on the Summer Monsoon in Southeast Asian*, 15–28. Kunming: Yunnan People’s Press.

Tang, X., B. Chen, L. Ping, and W. Qian. 2010. “Definition and Features of the North Edge of the East Asian Summer Monsoon.” *Journal of Meteorology. (English Edition)* 24 (1): 43–49.

Tang, X., W. H. Qian, and P. Liang. 2006. “Climatic Features of Boundary Belt for East Asian Summer Monsoon.” *Plateau Meteorology (in Chinese)* 25 (3): 375–381. doi:10.3321/j.issn:1000-0534.2006.03.003.

Tang, X., G. W. Sun, and W. H. Qian. 2007. *Study on the Northern Margin of the Asian Summer Monsoon*. (In Chinese). Beijing: Meteorological Press.

Tao, S. Y., and L. X. Chen. 1985. “The East Asia Summer Monsoon.” In *Proceedings of International Conference on Monsoon in the Far East*, 1–11.Tokyo, November 5–8.

Wang, H., and D. L. Li. 2011. “Correlation of Surface Sensible Heat Flux in the Arid Region of Northwestern China with the Northern Boundary of the East Asian Summer Monsoon and Chinese Summer Precipitation.” *Journal of Geophysical Research Atmospheres* 116 (D19): 1441–1458. doi:10.1029/2011jd015696.

Wang, A. Y., C. S. Wu, W. S. Lin, Y. Yang, R. Q. Feng, Z. M. Gu, and J. J. Liang. 1999. “The Definition of the Advance and Retreat of the Summer Monsoon in China.” *Plateau Meteorology (in Chinese)* 18 (3): 400–408. doi:10.3321/j.issn:1000-0534.1999.03.016.

Wu, C. G., H. S. Liu, and A. Xie. 2005. “Inter-decadal Characteristics of the Influence of Northward Shift and Intensity of Summer Monsoon on Precipitation over Northern China in Summer.” *Plateau Meteorology (in Chinese)* 24 (5): 656–665. doi:10.3321/j.issn:1000-0534.2005.05.002.

Wu, R. G., Z. P. Wen, S. Yang, and Y. Q. Li. 2010. “An Interdecadal Change in Southern China Summer Rainfall around 1992/93.” *Journal of Climate* 23: 2389–2403. doi:10.1175/2009jcli3336.1.

Xu, Y., and W. H. Qian. 2003. “Research on East Asian Summer Monsoon: A Review.” *Journal of Geographical Sciences (in Chinese)* 58 (S1): 138–146. doi:10.3321/j.issn:0375-5444.2003.z1.017.

Zeng, X., and E. Lu. 2004. “Globally Unified Monsoon Onset and Retreat Indexes.” *Journal of Climate* 17: 2241–2248.

Zhang, H. Y. 2017. “A Study on the Inter-decadal Change in the East Asian Summer Monsoon around the Early 1990s.” Doctoral dissertation, SunYat -sen University.

Zhang, H. Y., Z. P. Wen, R. G. Wu, et al. 2016. “Inter-decadal Changes in the East Asian Summer Monsoon and Associations with Sea Surface Temperature Anomaly in the South Indian Ocean.” *Climate Dynamic* 48 (3): 1–15. doi:10.1007/s00382-016-3131-6.

Zhu, Z., J. He, and L. Qi. 2012. “Seasonal Transition of East Asian Subtropical Monsoon and Its Possible Mechanism.” *Journal of Tropical Meteorology (English Edition)* 18 (3): 305–313. doi: 10.16555/j.1006-8775.2012.03.004.

Zhu, Z. W., J. He, S. Zhong, and K. Shang. 2013. “The Climatic Effect of Decadal Shift of the East Asian Atmospheric Circulation in Spring and Summer and Its Possible Causes.” *Acta Meteorologica Sinica (in Chinese)* 71 (3): 440–451. doi:10.11676/qxxb2013.037.

Zhu, Z., and T. Li. 2017. “Amplified Contiguous United States Summer Rainfall Variability Induced by East Asian Monsoon Interdecadal Change.” *Climate Dynamics* 2017: 1–14. doi:10.1007/s00382-017-3821-8.

Zhu, Z. W., T. Li, and J. He. 2014. “Out-of-Phase Relationship between Boreal Spring and Summer Decadal Rainfall Changes in Southern China.” *Journal of Climate* 27 (3): 1083–1099. doi:10.1175/JCLI-D-13-00180.1.

Zhu, C., B. Wang, W. Qian, and B. Zhang. 2012. “Recent Weakening of Northern East Asian Summer Monsoon: A Possible Response to Global Warming.” *Geophysical Research Letters* 39 (9): 9701. doi:10.10299/2012gl051155.