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Research Article

Weakening Relationship between East Asian Summer Monsoon and Asian-Pacific Oscillation after 1990s

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The East Asian summer monsoon (EASM), which is an important influencing summer climate of East Asia, is associated with large-scale change of the land-sea thermal contrast. The Asian-Pacific Oscillation (APO) can modulate the EASM because it not only represents the upper-tropospheric zonal land-sea thermal contrast over Asia and the Pacific region, but it also affects the sea surface temperature (SST) over the North Pacific, which can tune the land-sea thermal contrast for the EASM. This study revealed weakening of the APO-EASM relationship since the 1990s. It was found that the relationship between the APO and the EASM during 1948–1990 (1991–2016) was statistically significant (insignificant). Further study indicated that the APO was concurrent with significant positive SST in the central North Pacific and subtropical central-western Pacific during 1948–1990, which contributed to the shift of the Pacific Decadal Oscillation (PDO) from its cold to warm phase and led to a weakened EASM. The APO-related SST and atmospheric circulation anomalies were found statistically to be insignificant during 1991–2016, which indicates a weakening of influence of the APO on shift of the PDO, and even a weaker link to the EASM.

1. Introduction

The East Asian summer monsoon (EASM) has complex spatiotemporal features that are distinct from other monsoons such as the South Asian monsoon and the North American summer monsoon [1–3]. The spatial extent of the EASM covers areas of the tropics, subtropics, and mid-latitudes and its intensity, onset, and duration are the main factors that determine the summer climate anomalies in East Asia, which can cause various disasters such as floods, landslides, and drought [4–6].

Theoretically, the EASM is regarded as one of the consequences of the land-sea thermal contrast between East Asia and its adjacent oceans [7]. It is therefore highly important to estimate the magnitude of this land-sea thermal contrast because of its direct modulating action on interannual and interdecadal variability of the EASM [8]. Various indices have been defined based on pressure, potential height, and temperature to quantitatively describe the land-sea thermal contrast between East Asia and the adjacent oceans [9–12]. Recently, a new teleconnection pattern over the Asian-Pacific region during the boreal summer has been identified, that is, the Asian-Pacific Oscillation (APO), which reflects the zonal land-sea temperature difference between Asia and the North Pacific [13].

A significant positive relationship between the APO and the EASM variation has been documented [14–16]. However, both the EASM and the APO have interannual and interdecadal variations, and the question therefore arises: how stable is the long-term interrelationship between the

EASM and the APO? When the relationship between the EASM and the APO is unstable, climate predictability appears low; therefore, it is important to explore the long-term variation of the APO-EASM connection, which to the best of our knowledge has not previously been investigated thoroughly. Thus, in this paper, we first verify the sliding correlation coefficient between the EASM index (EASMI) and the APO index (APOI), and then we discuss a possible mechanism governing the relationship between the EASM and the APOI.

The remainder of the paper is organized as follows: Section 2 describes the data and the methods used, Section 3 introduces the results of this analysis, and Section 4 presents our conclusions.

2. Data and Methods

2.1. Data. This study focused on summer, which we considered to be the seasonal mean of June-August. The monthly mean datasets employed in this research include the following: (1) The National Centers for Environmental Prediction atmospheric reanalysis (1948–2016) with $2.5^{\circ} \times 2.5^{\circ}$ resolution [17], using variables including air temperature at 500, 400, 300, 250, and 200 hPa; meridional wind component and vertical velocity at 1000, 925, 850, 700, 600, 500, 400, 300, 250, and 200 hPa and the geopotential height (GPH) at 500 hPa to analyze characteristics of atmospheric circulation. The air temperatures at 500, 400, 300, 250, and 200 hPa are used to calculate the APOI. (2) The Centennial Institute Observation-Based Estimates of sea surface temperature data with $1.0^{\circ} \times 1.0^{\circ}$ resolution (1871–2016) from the Japan Meteorological Administration are used to analyze air-sea interaction [18].

To determine the variability of APO intensity, we adopted the definition of the APOI from Zhao et al. [13], which is the regional mean vertically averaged (500–200 hPa) eddy air temperature (T') difference between Eurasia (15–50°N, 60–120°E) and the central and eastern North Pacific (15–50°N, 180–120°W), i.e., APOI = T'(15–50°N, 60–120°E) − T'(15–50°N, 180–120°W). The EASMI is defined as an area-averaged dynamical normalized seasonality at 850 hPa within the East Asian monsoon domain (10–40°N, 110–140°E) [9].

2.2. Methods. As our concern in this study was on interdecadal variability, we adopted sliding correlations between the APOI and the EASMI. For the sliding correlations method, the length of sliding windows is a key factor for the analysis of changes in the APO-EASM relationship. Following the method in reference [19], we chose a 23-year sliding window. In addition, to study the relationship between the two variables, correlation, regression, and composite analyses were also used in our research.

3. Results

3.1. Interdecadal Shift in the APO-EASM Relationship. The time series of the summer mean APOI and EASMI during 1948–2016 are displayed in Figure 1. Clearly, both the APOI and the EASMI showed a significant interdecadal downward trend, which was significant at the confidence level of 0.05. This interdecadal downward trend was also confirmed by the low-pass filtering (0.125 Hz) analysis (not shown). It should be noted that although both the APOI and the EASMI have significant interdecadal weakening trends, it is important to explore whether there are differences between the APOI and the EASMI? Therefore, we further used the Mann–Whitney test to investigate whether there was a significant difference between the APOI and the EASMI—there was no significant difference between two indices at the confidence level of 0.05. In addition, both time series have dominant interannual variability with a correlation coefficient of 0.41 during the entire period. However, it is also noted that both the EASM and the APO became much weaker after the mid-1980s. To investigate decadal variation in the interannual relationship between the APO and the EASM, we calculated the sliding correlation coefficient between the two indices during 1948–2016 using a 23-year sliding window. Figure 2 shows that the APO and the EASM are significantly correlated before 1990, followed by obvious weakening of the correlation after 1991. The correlation coefficient between the APOI and the EASMI during 1948–1990 is 0.50 and is statistically significant; however, this decreases to 0.04 during 1991–2010. The variation of the correlation clearly indicates that the APO-EASM relationship has weakened in recent decades. Moreover, different lengths of sliding window have little difference (not shown). Based on these results, two periods (P1: 1948–1990 and P2: 1991–2016) were chosen to investigate the unstable relationship between the APO and the EASM.

To further validate the previous results, we compared the correlation distributions between the APOI and both 850 hPa meridional winds for the two periods (Figure 3). It can be seen from the figure that the APO-related EASM circulation showed remarkable differences between the two periods. During P1, a positive phase of the APOI corresponds to positive southerly wind anomalies over the South China Sea, eastern China, and northeast Asia, which represent a strong summer monsoon and increasing precipitation in both northern and southern China, particularly northern China (Figure 3(a)). In contrast, during P2, the positive correlation over East Asia is clearly decreased and there is no significant positive correlation in eastern China and the Korea–Japan region, and the regions with significant positive correlation are restricted to northeast China and the Yellow Sea area (Figure 3(b)).

These differences in the monsoon circulation between the two periods can be demonstrated further by considering the synthetic wind fields at a low level (850 hPa) (Figure 4). The APOI was first standardized to create weak and strong groups in both periods with standardized anomalies exceeding ±1, the results of which are shown in Table 1. In P1, the wind anomalies are more meridional over East Asia with a larger extension toward higher latitudes (Figure 4(a)), corresponding to a strong APO; conversely, the pattern exhibits opposite features corresponding to a weak APO (Figure 4(b)), indicative of a closer relationship between the

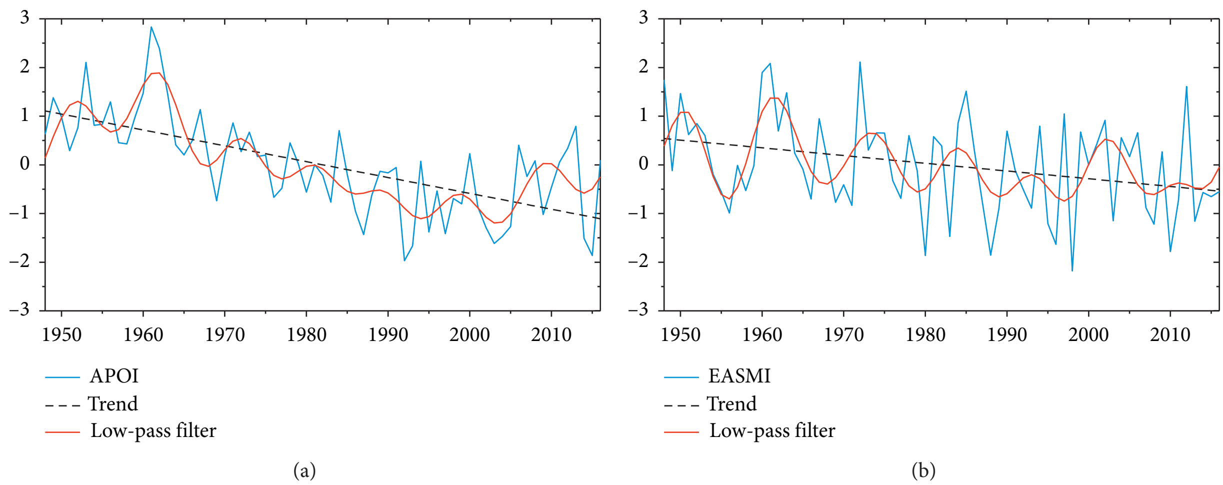


Figure 1: The interannual variation of the summer mean EASMI (a) and APOI (b) during 1948–2016.

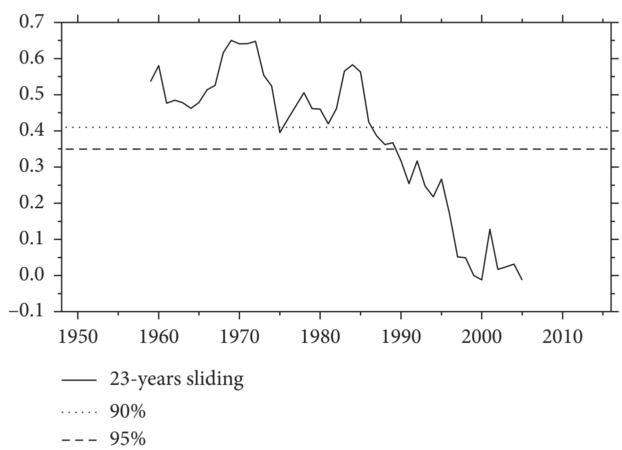


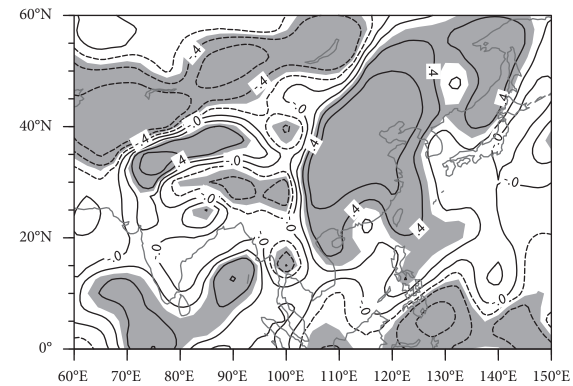
Figure 2: The 23-year sliding correlation coefficient between APOI and EASMI during 1948–2016. The long- and short-dashed lines indicate the values significant at the 90% and 95% confidence level, respectively.

APO and the EASM. However, the pattern is quite different during P2. The area of southerly wind anomalies only covers northeastern East Asia with respect to strong APO years during P2 (Figure 4(c)). Moreover, the northerly wind anomalies during weak APO years are much weaker (Figure 4(d)), suggesting a weaker relationship between the APO and the EASM during P2.

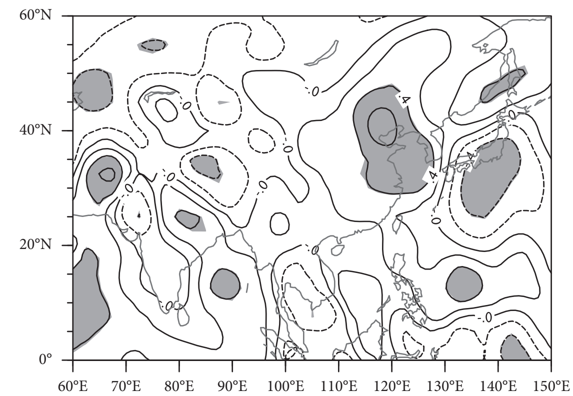
3.2. Discussion on the Possible Mechanisms. The above results indicate that the relationship between the APO and the EASM weakened after the 1990s. This identified weakening of the APO-EASM relationship prompts the following question: why has the APO-EASM relationship weakened since the 1990s? From the atmospheric perspective, the fundamental mechanism driving the EASM is the land-sea thermal contrast, and the change of sea surface temperature (SST) is a key factor influencing the strength of that thermal contrast. Therefore, the following analysis is based on the perspective of SST change.

Figure 5 shows the correlations between the APOI and SST in summer. It can be seen that positive values are dominant within the latitudinal zone of 30–50°N in the North Pacific, with a maximum value >0.4, suggesting that a strong (weak) APO corresponds to high (low) SST in the North Pacific. Zhou et al. [20] revealed that when the APO intensifies, the East Asian jet in the upper troposphere becomes weakened and an anomalous anticyclonic circulation with increased GPH prevails in the middle and lower troposphere over the North Pacific, which is advantageous for warming of North Pacific SST. In addition, warm water is advected northward because of zonal wind stress changes, which is also favorable for warm SST in the North Pacific. It is also evident from Figure 5 that the pattern of correlation between the APOI and SST is similar to the Pacific Decadal Oscillation (PDO). It shows that when the APO is stronger (weaker) than normal, higher (lower) SST in the North Pacific and lower (higher) SST in the equatorial central and eastern Pacific can be observed, which could possibly lead to a cold (warm) phase of the PDO. Thus, the APO might cause a change of the PDO phase by modifying Pacific SST, which subsequently influences the intensity of the EASM. Recent observations suggest a transition from a warm to cold PDO phase such that the land-sea thermal contrast has been enhanced, resulting in a stronger EASM [21].

It should be highlighted that if the relationship between the APO and Pacific SST was stable temporally, then it might have a stabilizing effect on EASM intensity through changing the PDO. However, the observed weakening of the relationship between the APO and the EASM since the 1990s implies that the connection between the APO and Pacific SST or the PDO might also be unstable. Therefore, we further analyzed the relationship between the APO and Pacific SST during P1 and P2 (Figure 6). For P1 (Figure 6(a)), significant positive correlations are centered over the central North Pacific and subtropical central western Pacific, with significant negative correlations on their southern and southeastern flanks. This pattern means that the PDO is likely to shift from its cold to warm phase because the APO continued to decrease during P1, which might have

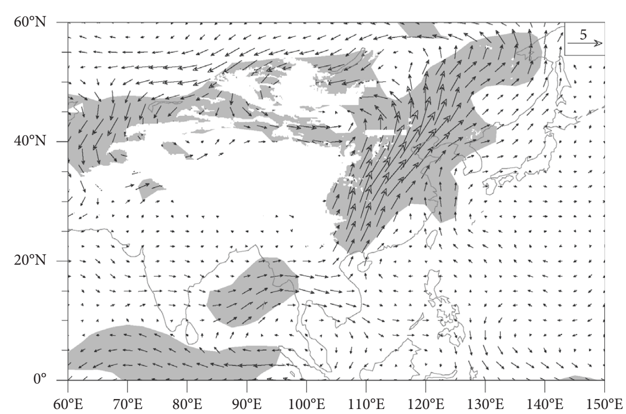


(a)



(b)

Figure 3: Spatial distribution of correlation coefficient between the APOI and 850 hPa meridional wind during (a) 1948–1990 and (b) 1991–2016. The shaded area indicates significant correlation at the 95% confidence level based on Student's *t*-test.



(a)

Figure 4: Continued.

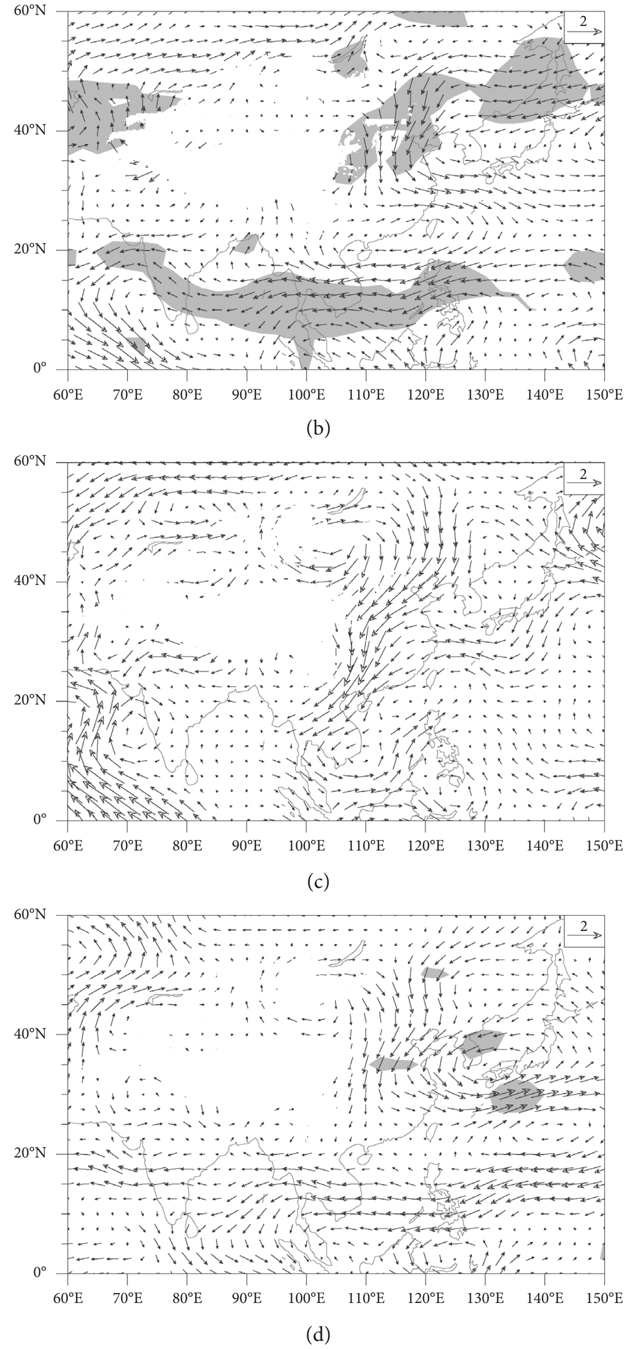


Figure 4: 850 hPa wind (vectors; scale in m s^{-1}) of strong (a) and weak (b) APO years during 1948–1990 and (c) strong and (d) weak APO years during 1991–2016. The shaded area indicates significant correlation at 95% confidence level based on Student's *t*-test.

contributed to the weaker EASM. In contrast, in P2, significant positive correlations are evident only over small areas of the central North and western Pacific, while significant positive correlations are found in the equatorial and subtropical eastern Pacific and offshore the North American coast (Figure 6(b)). This indicates a weakening influence of the APO on the shift of the PDO and a weaker link to the EASM.

These findings prompt another question: why did the APO-SST relationship change during period P2? It is most likely related to changes in the APO itself. The multiyear mean (P1 and P2) longitude-height cross section of the zonal vertical circulation along 15–50°N, averaged for summer, is shown in Figure 7. It is evident from the figure that three large-scale clockwise zonal vertical cells exist in the troposphere with one center in the lower troposphere over the North Pacific, another center in the lower troposphere over the North Atlantic, and the third center over the continent of Europe during both P1 and P2. It is found that because of the strong heating effect of the Tibetan Plateau (TP), upward

Table 1: Strong and weak APO years in two periods.

	Strong years	Weak years
P1	1949, 1953, 1956, 1960, 1961, 1962, and 1963	1969, 1976, 1980, 1983, 1986, 1987, and 1988
P2	2000, 2006, 2012, 2013, and 2016	1992, 1993, 2003, 2014, and 2015

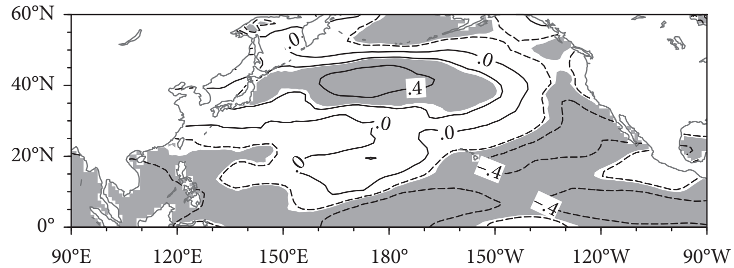


Figure 5: Spatial distribution of the correlation coefficient between the APOI and SST during 1948–2016. The shaded area indicates significant correlation at the 95% confidence level based on Student's t-test.

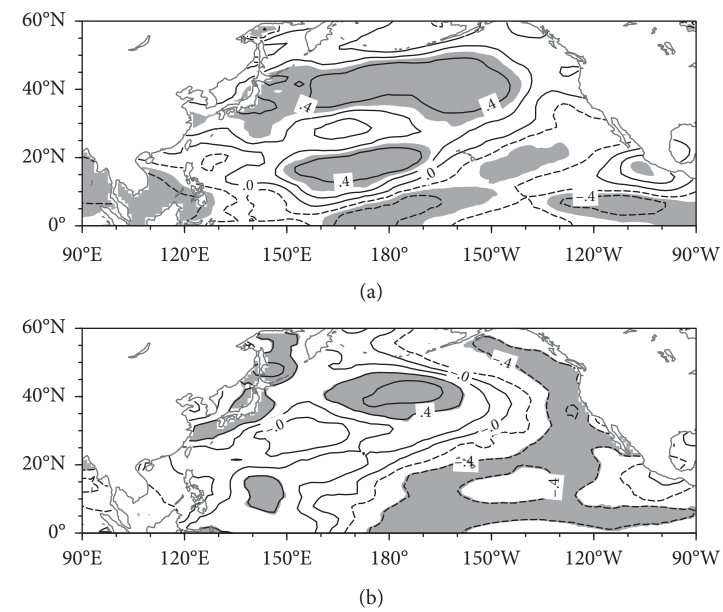


Figure 6: Same as Figure 5, but for (a) 1948–1990 and (b) 1991–2016.

motion mainly appears over the East Asian continent (EAC) (red dashed box) and the central Pacific (red solid box), with the strongest upward motion located over the TP and surrounding areas, while downward motion prevails over the eastern Pacific. We further compared the zonal vertical cell of P1 with that of P2. Results show that the updraft originating from the TP subsides along the Pacific, mainly affecting the region of 150°E–150°W in P1 (Figure 7(a)), while the downdraft is confined to 180–150°W in P2 (Figure 7(b)). This implies that the downdraft over the Pacific tends to move further eastward in P2 in comparison with P1. Thus, as the impact of the APO moves eastward, its influence on the East Asian climate decreases.

The low-level tropospheric wind field over the North Pacific plays a key role in the variation of local SST [21]. Generally, when a low-level anticyclonic (cyclonic) anomaly appears in the North Pacific, the North Pacific SST tends to become warmer (colder) than normal. Thus, we further explored the differences in the influence of the APO on SST during the two periods. First, according to the results of [22], we considered the SST averaged over the region 35–45°N and 150°E–150°W, as the North Pacific SST index (NPSSTI) to describe the North Pacific SST variations. Figure 8 displays regression maps of 850 hPa wind and 500 hPa GPH against the APOI and the NPSSTI for both periods. The most prominent circulation features associated with the APO anomaly are an anticyclonic circulation anomaly and increased 500 hPa GPH over the North Pacific in the regression pattern of the 850 hPa horizontal wind and the 500 hPa GPH against the APOI in P1 (Figure 8(a)). A similar

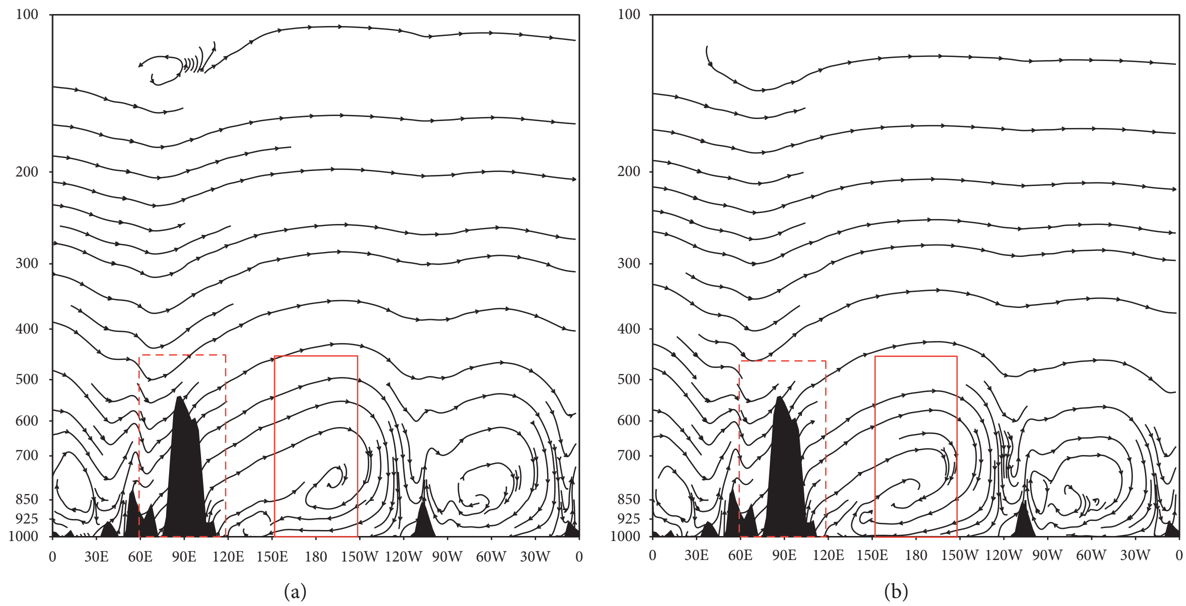


Figure 7: Longitude-height cross section of the climatology of vertical circulation along 15–50°N for (a) 1948–1990 and (b) 1991–2016. The black shaded area indicates the terrain.

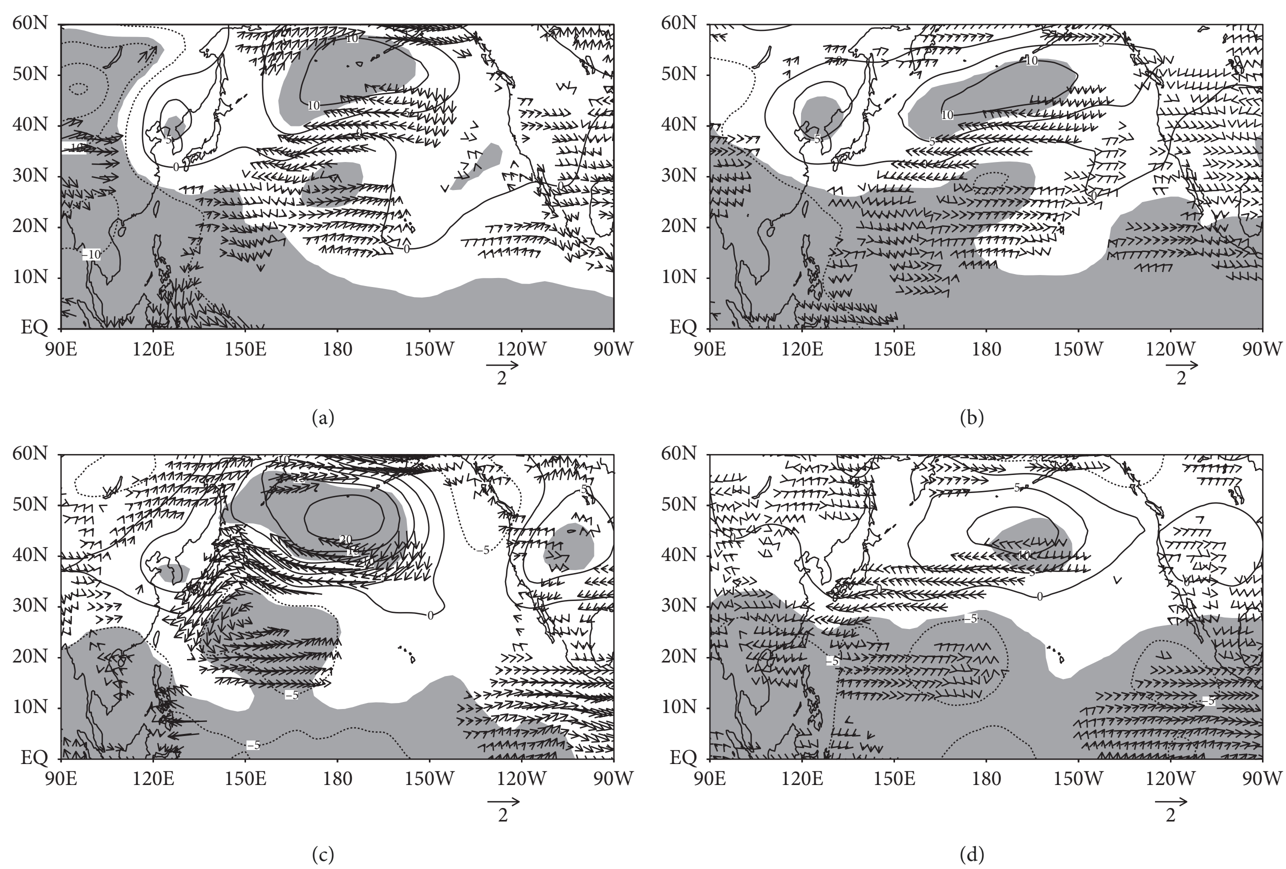


Figure 8: Regression maps of 850 hPa wind and 500 hPa GPH in (a) 1948–1990 and (c) 1991–2016 with regard to the APOI. Shaded area/vectors indicate that the GPH/wind anomalies are significant at the 90% confidence level based on Student's *t*-test. (b) and (d) are same are as for (a) and (c), but for the NPSSTI.

pattern was observed for the NPSSTI (Figure 8(b)). From the similar patterns of regression shown in Figures 8(a) and 8(b), it can be inferred that anomalies in the mid-low tropospheric circulation over the North Pacific are an important link between the APO and the North Pacific SST. During P2, approximately the same regression results were observed for the 850 hPa wind and the 500 hPa GPH against the APOI, with the areas of statistical significance over the North Pacific mainly retreating further southward and eastward in comparison with P1 (Figure 8(c)). Conversely, the regression results for the NPSSTI show a marked difference in P2 (Figure 8(d)), with the statistically significant areas moving further southward in the North Pacific region than in the former period, which significantly contributed to weakening of the link between the APO and the SST in the North Pacific, as well as the PDO. The regression analysis supports the previously proposed hypothesis that the influence of the APO on the PDO via the North Pacific SST was weakened during P2, which further resulted in weakening of the EASM-APO relationship after the 1990s.

4. Conclusions

Based on several gridded datasets, this work compared the correlation of the EASM with the APO between 1948–1990 and 1991–2016. The results revealed a remarkable difference in the correlation between the APO and the EASM after the 1990s. The possible mechanisms for the weakening of the APO-EASM relationship were discussed, and the main findings are summarized in the following.

The in-phase correlations between the APO and the EASM were found to be statistically significant during 1948–1990 but statistically insignificant during 1991–2016. The spatial distribution of the EASM-associated atmospheric variability also showed a distinct difference between the two periods. For P1, the wind anomalies were more meridional over East Asia and they had a larger extension to higher latitudes corresponding to a strong APO, which indicated a close relationship between the APO and the EASM. Conversely, for P2, the southerly wind anomalies only extended over northeastern East Asia with respect to a strong APO, indicative of a weaker APO-EASM relationship in comparison with P1.

The APO can cause a change in the PDO phase by modifying Pacific SST, which then influences the intensity of the EASM. However, this connection between the APO and Pacific SST or the PDO was found to be unstable. During P1, significant positive correlations were found to be centered over the central North Pacific and subtropical central western Pacific, with significant negative correlations on their southern and southeastern flanks, which contributed to the shift of the PDO from its cold to warm phase and further led to a weakened EASM. The APO-related SST and atmospheric circulation anomalies were found to be statistically insignificant during 1991–2016, which indicates a weakening influence of the APO on the shift of the PDO, and even a weaker link to the EASM.

The EASM is one of the most important systems affecting the East Asian climate, and it plays a key role in precipitation water vapor transport in East Asia. The results in this paper suggest that the APO provides an approach for studying the physical mechanism of the EASM. However, although the unstable relationship between the EASM and the APO was revealed, there are still some issues that need to be further discussed. For instance, the APO is closely related to precipitation in the middle and lower reaches of the Yangtze River in China [13]. How does this unstable relationship between the APO and the EASM affect the development of precipitation? Is there an unstable relationship between the APO and other specific phenomena which affect the East Asian climate (such as the El Niño–Southern Oscillation (ENSO), East Asian jet stream, South Asian high)? Such efforts will be helpful in improving our understanding of the unstable interaction between the APO and the East Asian climate.

In addition, many studies have focused on the instability of other different climate systems, such as the influence of the Arctic Oscillation on the East Asian climate through the relationship with both surface temperature and the East Asian jet stream which all show significant interdecadal differences [23, 24]. ENSO not only has an unstable influence on the climate of East Asia but also a significant influence on the climate change of the European continent in specific periods [1, 25–27]. For example, the relationship between ENSO and precipitation over northeastern China (western Russia surface temperature) after the mid-1990s (1980s) was strengthened during summer, which means that changes in climate elements in one place are not always affected by the same climate phenomena. Furthermore, some studies have also shown the significant impact of the decaying phase of El Niño on the Asian summer monsoon using CMIP5, indicating that numerical modeling is a valuable way to explore the instability [28]. For these reasons, studying the unstable relationship between two weather systems will provide new ideas for understanding the physical mechanisms existing under the different climate conditions in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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References

[1] W. Huijun, "The instability of the East Asian summer monsoon–ENSO relations," *Advances in Atmospheric Sciences*, vol. 19, no. 1, pp. 1–11, 2002.

[2] Y. Ding and J. C. L. Chang, "The East Asian summer monsoon: an overview," *Meteorology and Atmospheric Physics*, vol. 89, pp. 117–142, 2005.

[3] H. Zhang, Z. Wen, R. Wu, Z. Chen, and Y. Guo, "Inter-decadal changes in the East Asian summer monsoon and associations with sea surface temperature anomaly in the South Indian Ocean," *Climate Dynamics*, vol. 48, no. 3-4, pp. 1125–1139, 2017.

[4] M. Kwon, J. Jhun, and K. Ha, "Decadal changes in East Asian summer monsoon circulation after the mid-1990s," *Geophysical Research Letters*, vol. 34, no. 21, pp. 377–390, 2007.

[5] Y. Ding, Z. Wang, and Y. Sun, "Inter-decadal variation of the summer precipitation in East China and its association with decreasing Asian summer monsoon. Part I: observed evidences," *International Journal of Climatology*, vol. 28, no. 9, pp. 1139–1161, 2008.

[6] H. Li, A. Dai, T. Zhou, and J. Lu, "Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950–2000," *Climate Dynamics*, vol. 34, no. 4, pp. 501–514, 2010.

[7] Y. Kamae, M. Watanabe, M. Kimoto, and H. Shiogama, "Summertime land-sea thermal contrast and atmospheric circulation over East Asia in a warming climate-part I: past changes and future projections," *Climate Dynamics*, vol. 43, no. 9-10, pp. 2553–2568, 2014.

[8] C. Chou, "Land-sea heating contrast in an idealized Asian summer monsoon," *Climate Dynamics*, vol. 21, no. 1, pp. 11–25, 2003.

[9] L. Jianping and Z. Qingcun, "A new monsoon index and the geographical distribution of the global monsoons," *Advances in Atmospheric Sciences*, vol. 20, no. 2, pp. 299–302, 2003.

[10] G. Huang, "An index measuring the interannual variation of the East Asian summer monsoon-The EAP index," *Advances in Atmospheric Sciences*, vol. 21, no. 1, pp. 41–52, 2004.

[11] C. Zhu, W. S. Lee, H. Kang, and C. K. Park, "A proper monsoon index for seasonal and interannual variations of the East Asian monsoon," *Geophysical Research Letters*, vol. 32, no. 2, pp. 287–294, 2005.

[12] B. Wang, Z. Wu, J. Li et al., "How to measure the strength of the East Asian summer monsoon," *Journal of Climate*, vol. 21, no. 17, pp. 4449–4463, 2008.

[13] P. Zhao, Y. Zhu, and R. Zhang, "An Asian-Pacific teleconnection in summer tropospheric temperature and associated Asian climate variability," *Climate Dynamics*, vol. 29, no. 2-3, pp. 293–303, 2007.

[14] X. Zhou, P. Zhao, and G. Liu, "Asian-Pacific oscillation index and variation of East Asian summer monsoon over the past millennium," *Chinese Science Bulletin*, vol. 54, no. 20, pp. 3768–3771, 2009.

[15] P. Zhao, Z. Cao, and J. Chen, "A summer teleconnection pattern over the extratropical Northern Hemisphere and associated mechanisms," *Climate Dynamics*, vol. 35, no. 2-3, pp. 523–534, 2010.

[16] B. Zhou and P. Zhao, "Influence of the Asian-Pacific oscillation on spring precipitation over central Eastern China," *Advances in Atmospheric Sciences*, vol. 27, no. 3, pp. 575–582, 2010.

[17] E. Kalnay, M. Kanamitsu, R. Kistler et al., "The NCEP/NCAR 40-year reanalysis project," *Bulletin of the American Meteorological Society*, vol. 77, no. 3, pp. 437–471, 1996.

[18] S. Hirahara, M. Ishii, and Y. Fukuda, "Centennial-scale sea surface temperature analysis and its uncertainty," *Journal of Climate*, vol. 27, no. 1, pp. 57–75, 2014.

[19] S. He, H. Wang, Y. Gao, and F. Li, "Recent intensified impact of December arctic oscillation on subsequent January temperature in Eurasia and North africa," *Climate Dynamics*, vol. 52, no. 1-2, pp. 1077–1094, 2019.

[20] B. Zhou, X. Cui, and P. Zhao, "Relationship between the Asian-Pacific oscillation and the tropical cyclone frequency in the Western North Pacific," *Science in China Series D: Earth Sciences*, vol. 51, no. 3, pp. 380–385, 2008.

[21] Y. Zhu, H. Wang, W. Zhou, and J. Ma, "Recent changes in the summer precipitation pattern in East China and the background circulation," *Climate Dynamics*, vol. 36, no. 7-8, pp. 1463–1473, 2011.

[22] B. Zhou, P. Zhao, and X. Cui, "The relationship between the Asian-Pacific oscillation changes and SST anomalies in the North Pacific," *Chinese Science Bulletin*, vol. 55, no. 1, pp. 74–79, 2010.

[23] Y. Liu, S. He, F. Li, H. Wang, and Y. Zhu, "Interdecadal change between the arctic oscillation and East Asian climate during 1900–2015 winters," *International Journal of Climatology*, vol. 37, no. 14, pp. 4791–4802, 2017.

[24] Y. Liu, S. He, F. Li, H. Wang, and Y. Zhu, "Unstable relationship between the arctic oscillation and East Asian jet stream in winter and possible mechanisms," *Theoretical and Applied Climatology*, vol. 135, no. 1-2, pp. 13–27, 2019.

[25] C. Sun, J. Li, and R. Ding, "Strengthening relationship between ENSO and Western Russian summer surface temperature," *Geophysical Research Letters*, vol. 43, no. 2, pp. 843–851, 2016.

[26] T. Han, H. Wang, and J. Sun, "Strengthened relationship between eastern ENSO and summer precipitation over Northeastern China," *Journal of Climate*, vol. 30, no. 12, pp. 4497–4512, 2017.

[27] F. Li, H. Wang, and J. Liu, "The strengthening relationship between Arctic oscillation and ENSO after the mid-1990s," *International Journal of Climatology*, vol. 34, no. 7, pp. 2515–2521, 2014.

[28] G. Srinivas, J. S. Chowdary, C. Gnanaseelan et al., "Impact of differences in the decaying phase of El Niño on South and East Asia summer monsoon in CMIP5 models," *International Journal of Climatology*, 2019.