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# Influence of the Asian-Pacific Oscillation on Spring Precipitation over Central Eastern China

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**ABSTRACT**

The linkage between the Asian-Pacific oscillation (APO) and the precipitation over central eastern China in spring is preliminarily addressed by use of the observed data. Results show that they correlate very well, with the positive (negative) phase of APO tending to increase (decrease) the precipitation over central eastern China. Such a relationship can be explained by the atmospheric circulation changes over Asia and the North Pacific in association with the anomalous APO. A positive phase of APO, characterized by a positive anomaly over Asia and a negative anomaly over the North Pacific in the upper-tropospheric temperature, corresponds to decreased low-level geopotential height ($H$) and increased high-level $H$ over Asia, and these effects are concurrent with increased low-level $H$ and decreased high-level $H$ over the North Pacific. Meanwhile, an anticyclonic circulation anomaly in the upper troposphere and a cyclonic circulation anomaly in the lower troposphere are introduced in East Asia, and the low-level southerly wind is strengthened over central eastern China. These changes provide advantageous conditions for enhanced precipitation over central eastern China. The situation is reversed in the negative phase of APO, leading to reduced precipitation in this region.

**Key words**: Asian-Pacific oscillation, precipitation over central eastern China, Asia and the North Pacific, atmospheric circulations

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## 1. Introduction

Spring is the time for farms to plant agricultural crops and for the winter wheat to grow. So, precipitation variations in this season are very crucial to the agricultural economy in central eastern China. Moderate precipitation is beneficial for the planting and growing of crops in this region, although the main rain belt is located in South China during spring. However, due to deficiencies in the precipitation, China often suffers from droughts, which bring severe damage to the agriculture. Observational records for the past 50 years show a drying trend of the spring precipitation over central eastern China (Hu et al., 2003; Yang and Lau, 2004; Zhai et al., 2005). Thus, the cause of spring droughts in this region is a subject of considerable scientific and practical interest.

So far, there have been many studies devoted to climatic precipitation variability in China, and a few major influences have been highlighted, including sea surface temperature (Wang et al., 2000; Lau and Wu, 2001; Gong and Ho, 2002; Wang, 2002a), the western Pacific subtropical high (Wang and Wu, 1997), the South Asian high (Zhang and Wu, 2001), Eurasian snow cover (Wang and Zeng, 1994), sea ice extent (Xue et al., 2003a; Zhao et al., 2004), East Asian upper-tropospheric air temperature (Yu et al., 2004), the Hadley circulation (Zhou and Wang, 2006; Zhou and Cui, 2008), the Antarctic Oscillation (Gao et al., 2003; Nan and Li, 2003; Xue et al., 2003b, c; Wang and Fan,

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2005; Fan, 2006) and the Arctic Oscillation (Gong and Ho, 2003), etc. However, previous works have focused on summer precipitation, and little attention has been paid to the spring precipitation over central eastern China.

Although Yang and Lau (2004) proposed that the variations of the spring precipitation over central eastern China are primarily linked to the sea surface temperature in the warm pool and the Indian Ocean on the interannual time scale, and Xin et al. (2006, 2008) attributed the spring droughts to the upper-tropospheric cooling over central China on the interdecadal time scale, the mechanism governing spring precipitation variability over central eastern China is far from clear since it is affected by many factors over a wide range of spatial and temporal scales. Thus, seeking other factors that have possible effects on the spring precipitation is potentially important, to better recognize the causes of spring droughts in China. Recently, a new teleconnection pattern over the Asian-Pacific region, namely, the Asian-Pacific oscillation (APO) has been identified, which exists in spring, summer, and autumn (Zhao et al., 2007a, 2008a; Nan et al., 2009). It is also documented that the summer APO exerts significant contemporaneous impacts on climate, such

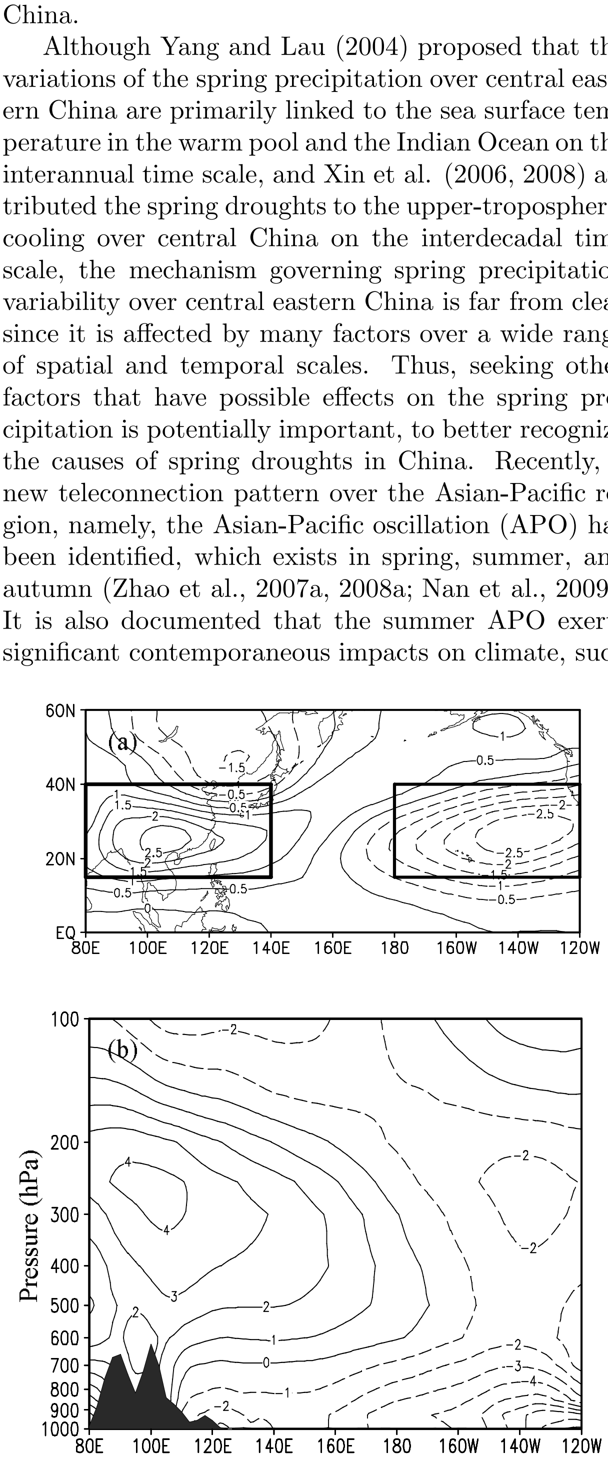


**Fig. 1.** (a) Climatology of the spring upper-tropospheric (500–200 hPa) eddy temperature ($T'$) (°C) for the period 1951–2005. (b) Longitude–height cross-section of $T'$ (°C) along 27.5°N. Shaded areas denote mountains.

as for the precipitation in China (Zhao et al., 2007a, 2008a), the tropical cyclone frequency in the western North Pacific (Zhou et al., 2008), and the sea surface temperature in the North Pacific (Zhou et al., 2009).

Because the spring rainfall over eastern China may be produced by the strengthened southerly winds over southern China that are associated with the thermal contrast between the East Asian land and its adjacent oceans (e.g., He et al., 2007; Zhao et al., 2007b, 2009) and the APO may reflect the variability of the thermal contrast between Asia and the North Pacific, it is necessary to examine whether an anomaly of the spring APO has an effect on the spring precipitation in China. This is the motivation of the present study.

## 2. Data

The data sets employed in the study include National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data (Kalnay et al., 1996) with a resolution of 2.5°×2.5°, and the Chinese 160-station monthly precipitation data derived from the China Meteorological Administration (CMA) for 1951–2005. "Spring" in this study refers to April–May (AM) when notable droughts can occur over central eastern China (Xin et al., 2006).

## 3. Definition of the Asian-Pacific Oscillation

Firstly, we give a simple description on the spring APO, i.e., the atmospheric teleconnection pattern in tropospheric temperature between Asia and the North Pacific. Figure 1a displays the AM mean climatological distribution of the vertically averaged (500–200 hPa) eddy air temperature ($T'$). Here, $T' = T - [T]$ where $T$ is the air temperature and $[T]$ is the zonal mean of the air temperature. Since air temperature, which decreases from the equator to the pole, mainly exhibits a meridional contrast, $T'$ is a good measure for reflecting zonal thermal differences. As shown in Fig. 1a, positive $T'$ values appear over Asia, while negative $T'$ values emerge over the central and eastern North Pacific. On the vertical cross-section of the climatological spring $T'$ along 27.5°N (Fig. 1b), positive and negative $T'$ values are also observed in the troposphere over Asia and the North Pacific, respectively, with centers in the upper troposphere, suggesting that it is reasonable to use the $T'$ averaged from 500 to 200 hPa to represent the mean state of the upper-tropospheric temperature.

Given the locations of the positive and the negative centers outlined by the rectangle in Fig. 1a, we define the AM mean upper-tropospheric (500–200 hPa thickness-average) $T'$ in the regions (15°–40°N, 80°–140°E)/(15°–40°N, 180°–120°W) as Asian/Pacific $T'$ indices to describe the tropospheric temperature anomaly for the Asia/Pacific regions. It follows that the Asian $T'$ index is highly negatively correlated to the Pacific $T'$ index, with a correlation coefficient of −0.67 (significant at 0.1% level) during 1951–2005. Therefore, there exists a strong out-of-phase relationship in $T'$ between Asia and the North Pacific. That is, when the tropospheric eddy temperature over Asia increases (decreases), the tropospheric eddy temperature over the North Pacific decreases (increases). This out-of-phase relationship can also be detected from an empirical orthogonal function analysis (Zhao et al., 2008a; Nan et al., 2009). Such a zonal seesaw pattern of the tropospheric temperature over the Asian–Pacific region was first noted by Zhao et al. (2007a, 2008a), who named the pattern the APO. In essence, the APO reflects a zonal tropospheric thermal difference between Asia and the North Pacific. When the APO is intensified (weakened), the thermal difference tends to be enhanced (diminished). The formation of APO anomalies may be associated with the zonal vertical circulation caused by the difference of the solar radiative heating between the Asian continent and the North Pacific (Zhao et al., 2008a). For more details about the physical implication of the APO, readers may refer to the Zhao et al. (2007a, 2008a).

In the present study, the arithmetic difference between the Asian and Pacific $T'$ indices is defined as the APO index to measure its intensity, i.e., APO index=$T'_{15^\circ-40^\circ\mathrm{N},\ 80^\circ-140^\circ\mathrm{E}} - T'_{15^\circ-40^\circ\mathrm{N},\ 180^\circ-120^\circ\mathrm{W}}$. The APO index has a significant positive correlation (0.91) with the Asian $T'$ index and a significant negative correlation (−0.91) with the Pacific $T'$ index, demonstrating that the APO index captures the variations of the Asian and Pacific $T'$ indices and their difference very well.

## 4. APO and precipitation over central eastern China

Figure 2a shows the simultaneous correlations between the APO index and the precipitation in China during spring. It is found that there exists a significant positive correlation, with the maximum value above 0.4 over central eastern China, implying that more (less) precipitation over central eastern China corresponds to a stronger (weaker) spring APO. In order to examine the linkage of the APO with the precipitation over a larger region, we also computed the correlations between the APO index and the CPC (Climate Prediction Center) rainfall data in spring. Positive correlations are observed over central eastern China, consistent with Fig. 2a, and extend eastward to Japan. Additionally, negative correlations emerge in the North Pacific (Fig. 2b). However, in this study we concentrate the emphasis on the relationship between the APO and the precipitation over central eastern China.

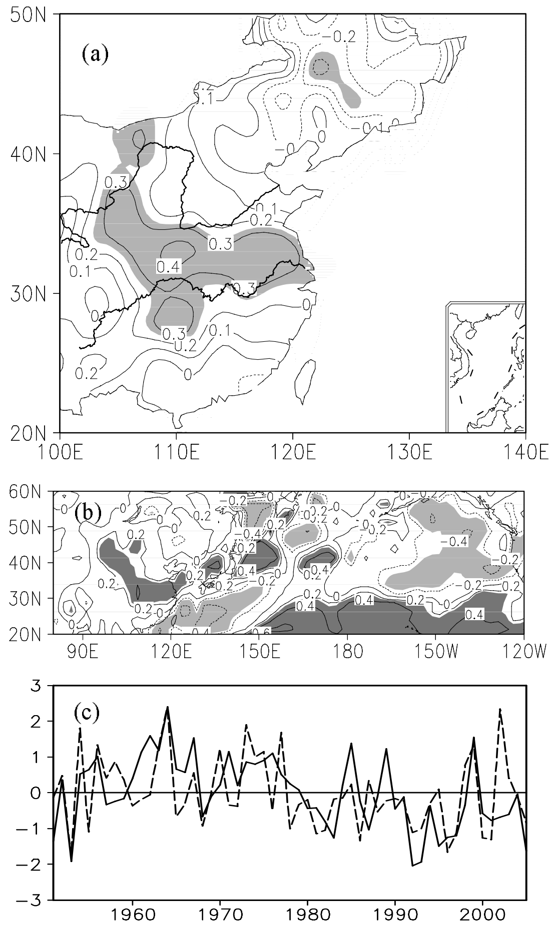


**Fig. 2.** (a) Correlations between the APO index and the precipitation over China in spring. Areas above the 5% significance level are shaded. (b) Same as in (a), but for the correlations with CPC rainfall data. (c) Time series of the normalized APO index (solid line) and the CECP index (dashed line).

The mean precipitation at 18 stations within central eastern China is chosen to represent a spring rainfall index for this region (hereafter, CECP). Its variation is found to be consistent with that of the APO index (Fig. 2c). Both exhibit obvious interannual and interdecadal variability. Before the late 1970s, APO tends toward positive polarity with a warmer $T'$ over Asia and a colder $T'$ over the North Pacific, indicating the APO is relatively strong. After the late 1970s, the APO tends toward negative polarity with a colder $T'$ over Asia and a warmer $T'$ over the North Pacific, indicating the APO became relatively weaker. The case for CECP is rather similar, with more precipitation

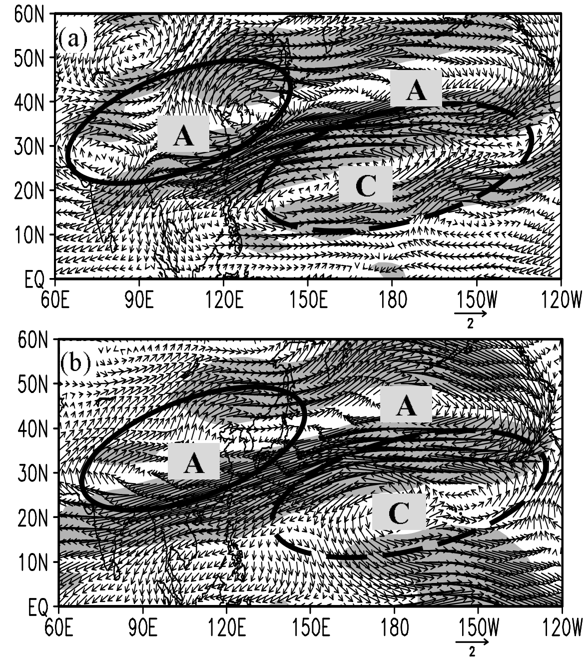


**Fig. 3.** Regressions of the 200 hPa horizontal wind (m $s^{-1}$) against (a) the CECP index and (b) APO index. Areas above the 5% significance level are shaded. "A" and "C" in the figure indicate the anticyclonic and cyclonic circulation systems, respectively.

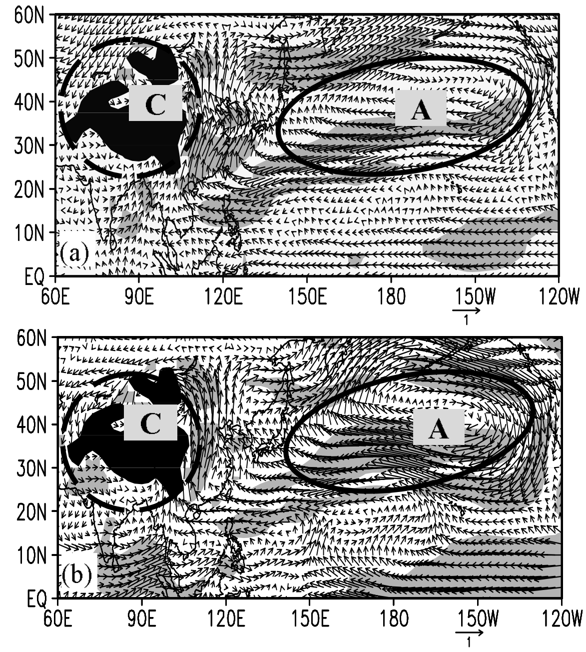


**Fig. 4.** Same as in Fig. 3, but for 850 hPa. The black shading denotes the location of the Tibetan Plateau.

over central eastern China before 1978, whereas there was less precipitation over central eastern China after 1978. Such a decadal scale variation hints that the spring APO shifting from its positive phase to negative phase may have partially contributed to the prominent reduction of the precipitation over central eastern China since the 1980s. The APO-CECP correlations for the non-detrended and detrended results are 0.51 and 0.48, respectively, with both results significant at 1% level. Therefore, the in-phase APO-CECP relationship is quite robust on both the interannual and interdecadal time scales.

What are the atmospheric circulation changes behind the APO-CECP relationship? Figures 3 and 4 plot the regressions of the horizontal winds with respect to the CECP and APO indices at 200 hPa and 850 hPa, respectively. In association with the increased precipitation (by one standard deviation) over central eastern China, an anticyclonic circulation anomaly is predominant over Asia and a cyclonic circulation anomaly is dominant south of the North Pacific at 200 hPa (Fig. 3a). Concurrently, at 850 hPa, an anomalous cyclonic circulation dominates over Asia and an anomalous anticyclonic circulation predominates over the North Pacific, concomitant with the southerly anomaly occupying central eastern China (Fig. 4a). Impressively, the regression pattern against the APO index at the high-level and the low-level shown in Figs. 3b and 4b resembles that against the CECP index. This evidence supports the in-phase APO-CECP relationship. Therefore, the APO can cause precipitation anomalies over central eastern China via its impacts on the atmospheric circulations over Asia and the North Pacific in the upper and lower troposphere.

To perform a composite analysis on the atmospheric circulations related to the interannual variability of the spring APO, 8 extreme years (1962, 1964, 1967, 1971, 1976, 1985, 1989, 1999) are selected for the strong APO cases and 7 extreme years (1951, 1953, 1983, 1992, 1993, 1995, 2005) for the weak APO cases. The longitude–height cross-section of the composite differences of $T$ and $H$ are presented in Fig. 5. A strong APO is accompanied by positive $T$ anomalies over Asia and negative $T$ anomalies over the North Pacific, with their centers located between 300–200 hPa. According to the equation of static equilibrium, the increase (decrease) in temperature within the air column may result in a decrease (increase) in the lower-level pressure and an increase (decrease) in the upper-level pressure via the expansion (contraction) of the air column. Thus, over Asia, due to the warming troposphere, the low-level $H$ is reduced while the high-level $H$ is enhanced. Over the North Pacific, the situation is reversed, with increased low-level $H$ and decreased high-level $H$ due to the cooling troposphere.

Figure 6 further depicts the distribution of the geopotential height corresponding to the strong and

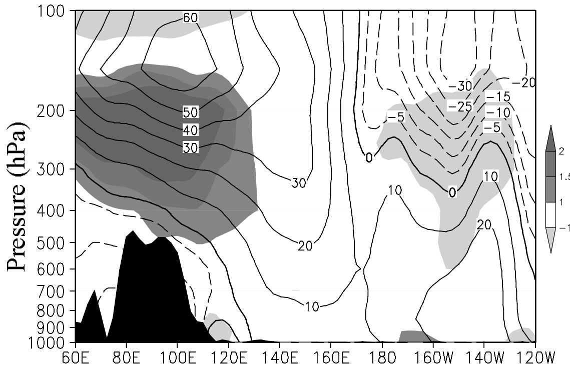


**Fig. 5.** Longitude–height cross-section of the composite difference of the geopotential height (m) and the air temperature (°C) along 32.5°N. The black shading denotes mountains, the lighter shadings indicate the air temperature, and the contours show the geopotential height.

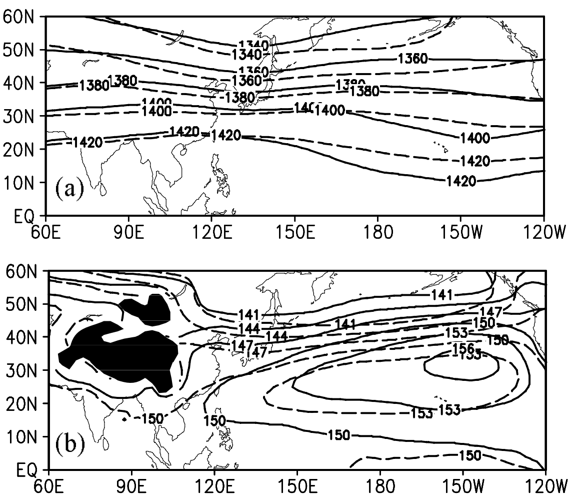


**Fig. 6.** Composite distribution of the geopotential height (×10 m) at (a) 150 hPa and (b) 850 hPa, corresponding to the strong (solid line) and weak (dashed line) APO years. The black shading denotes the location of the Tibetan Plateau.

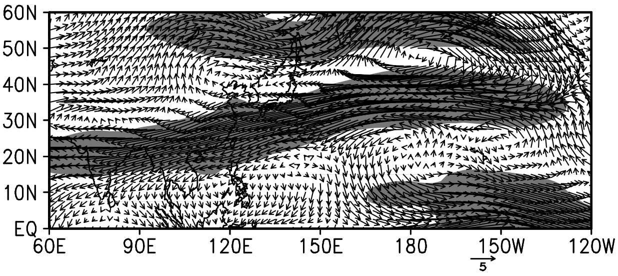


**Fig. 7.** Composite difference of the horizontal wind (m $s^{-1}$) at 200 hPa between strong and weak APO years. Areas above the 5% significance level are shaded.

weak APO years. At 150 hPa (Fig. 6a), the 14 200 m and 14 000 m contours in the strong APO cases move northward over Asia and southward over the North Pacific as compared to the weak APO cases, implying that $H$ over Asia is higher and the Pacific trough is deeper in the strong APO years than in the weak APO years. At 850 hPa (Fig. 6b), the 1470 m and 1440 m contours over Asia in the strong APO cases shift to the south of those in the weak APO years, indicating that the $H$ in this region is lowered (elevated) when the spring APO index is above (below) the normal. Over the Pacific, the positive phase of APO corresponds to the intensified, as well as northward-located, Pacific subtropical high, and vice versa.

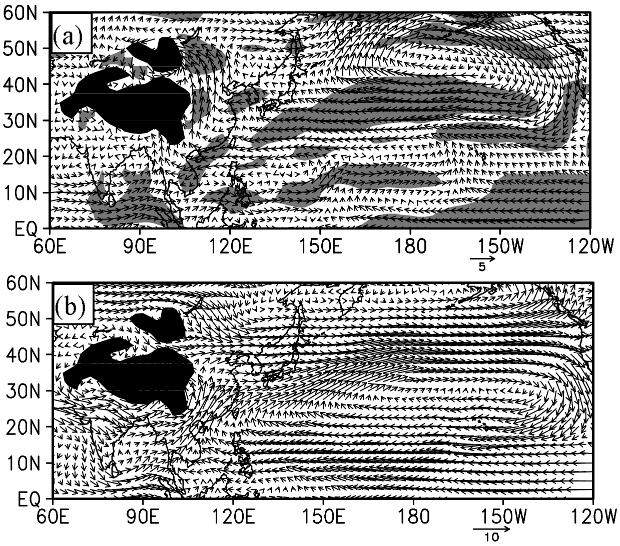


**Fig. 8.** (a) Composite difference of the horizontal wind (m $s^{-1}$) at 850 hPa between strong and weak APO years. Areas above the 5% significance level are shaded. (b) Climatology of the horizontal wind at 850 hPa in spring. The black shading denotes the location of the Tibetan Plateau.

Consistent with the significant change of the geopotential height, the high- and low-level horizontal winds vary remarkably, as well. An anomalous anticyclonic circulation over Asia and an anomalous cyclonic circulation south of the North Pacific are introduced in the upper troposphere (Fig. 7), accompanied with a cyclonic circulation anomaly over Asia and an anticyclonic circulation anomaly over the North Pacific in the lower troposphere (Fig. 8a). The distribution of horizontal wind anomalies conforms to the regression pattern shown in Figs. 3b and 4b, and corresponds to atmospheric circulations conducive to more precipitation over central eastern China (Figs. 3a and 4a). In addition, anomalous southerly winds prevail over central eastern China at 850 hPa. In the climatology (Fig. 8b), a trough emerges near the east boundary of the Tibetan Plateau and the subtropical high appears in the Pacific. Southerly winds between them are

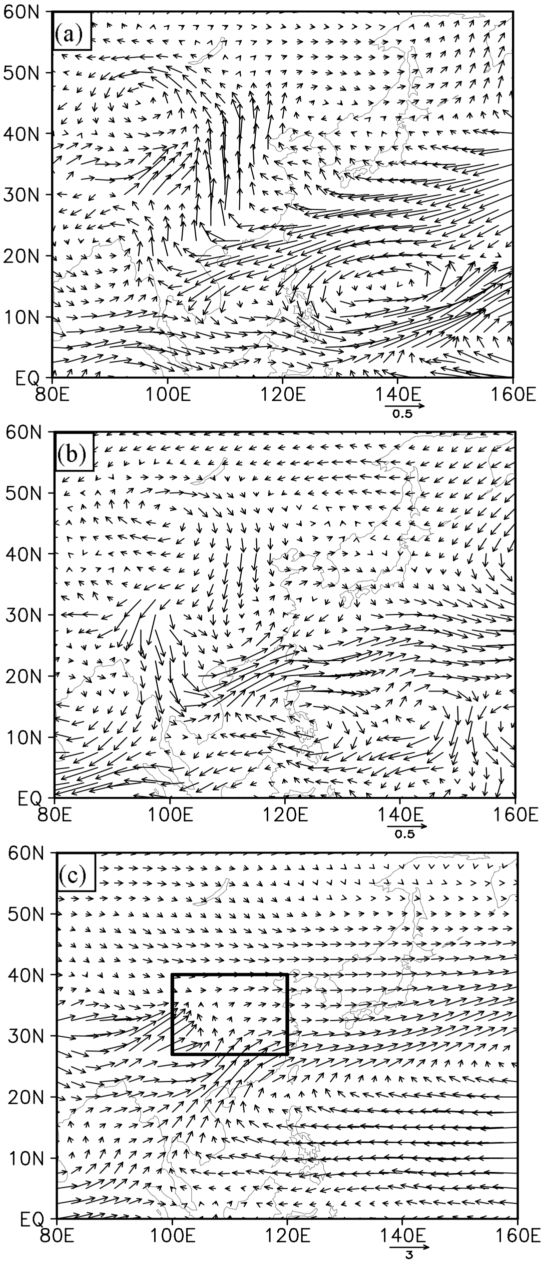


**Fig. 9.** The spring vertically integrated water vapor transport flux anomaly (100 kg m$^{-1}$ s$^{-1}$) corresponding to (a) strong and (b) weak APO years. (c) Climatology of the spring vertically integrated water vapor transport flux.

found to prevail over eastern China, and northwesterly winds are situated to the north of this region in spring. Such a flow pattern in April–May has been called the spring monsoon by Wang (2002b). In fact, southerly winds exceeding 2 m s$^{-1}$ begin earliest over southeastern China (20°–30°N) and strengthen gradually from spring to the early summer, as they extend northward (Zhao et al., 2007b, 2008b; Zhou and Zhao, 2009). This branch of the low-level southerly flow is proven to be important for the occurrence of the spring precipitation. If the southerly wind is stronger than normal, more rainfall is inclined to occur in the Yangtze and Huaihe River valley, and vice versa (Zhao et al., 2009).

Moreover, the strengthened southerly flow also increases the transport of water vapor toward eastern China. This can be confirmed by examining the water vapor transport flux anomaly integrated vertically from 1000 hPa to 500 hPa corresponding to the strong and weak APO years. Obviously, in the strong APO years (Fig. 9a), anomalous northward water vapor transport is observed over central eastern China. Inversely, in the weak APO years (Fig. 9b), anomalous water vapor transport to the south is seen over central eastern China. It is suggested that the water vapor transport toward central eastern China in relation to the strong (weak) APO is enhanced (reduced), since the water vapor is transported from the south toward the target region under climatological mean conditions (Fig. 9c).

Therefore, when the spring APO is in the positive (negative) phase, the low-level southerly winds are strengthened (weakened), which can result in more (less) precipitation over central eastern China through enhancement (reduction) of the water vapor transport. In order to verify the important role of the southerly airflow in the APO-CECP linkage, we calculated the correlations of the meridional wind averaged in the region (25°–40°N, 105°–120°E) with the APO and CECP indices. Their correlation coefficients are 0.48 and 0.45, respectively, and both are significant at the 1% level. After removing their respective linear trends, the corresponding correlation coefficients are 0.33 and 0.45, which are still significant at the 5% level. This demonstrates that the low-level southerlies do play a key role in connecting the APO to the precipitation over central eastern China.

## 5. Conclusion and discussion

The influence of the spring APO on the precipitation over central eastern China in spring is investigated in this study. The results delineate that there is a significant in-phase relationship between the APO and CECP, with the correlation coefficients being 0.51 and 0.48 respectively for the non-detrended and detrended index time series during 1951–2005. If the APO is stronger (weaker) than normal, more (less) precipitation will occur over central eastern China. Additionally, both the APO and CECP indices exhibit interdecadal variability with a transition in the late 1970s, having previously been in a positive phase before progressing into a negative phase after this time. Such a decadal variation reveals that the apparent reduction of the spring precipitation over central eastern China since the 1980s may be partially attributed to the APO shifting from the positive phase to the negative phase.

The underlying mechanism responsible for the APO-CECP linkage is further identified. When the APO is in the positive phase, the positive/negative $T$ anomalies over Asia/the North Pacific are prominent in the upper troposphere. Correspondingly, the low-level $H$ is decreased/increased while the high-level $H$ is increased/decreased over Asia/the North Pacific. Accordingly, the anticyclonic circulation anomaly in the upper troposphere and the cyclonic circulation anomaly in the lower troposphere are introduced in East Asia, and the low-level southerly wind is strengthened over central eastern China, favorable for the increase of the precipitation over central eastern China. The opposite situations are applicable for the negative APO, and thus the drought happens in this region.

In conclusion, the interannual variability of the spring APO can exert significant effects on the precipitation variations, with the positive APO corresponding to more precipitation over central eastern China. Note that the summer APO also affects the summer rainfall. When the summer APO is strong, the rainfall increases in eastern China between 35°N and 40°N, and decreases in the Yangtze River valley (Zhao et al., 2007a, 2008a). Comparing the distribution of the precipitation related to the APO in spring with that of summer, we can find that the positive anomaly of the precipitation in spring is situated to the south of that in summer. The reason for this difference is that APO in spring is located further southward than that in summer (Zhao et al., 2008a; Nan et al., 2009).

Additionally, a distinctive upper-tropospheric cooling over East Asia in spring and summer has been documented and is thought to play important roles in the rainfall on the interdecadal time scale (Yu et al., 2004; Xin et al., 2006, 2008; Ha et al., 2009). Because the APO is composed of the upper-tropospheric temperature changes over both Asia and the North Pacific, this tropospheric cooling over East Asia is related to APO and may be a regional response to decadal changes of the global atmospheric circulation. Moreover, Zhao et al. (2008a) illustrated that using the zonal temperature difference between the East Asian continent and the North Pacific is better than only using temperature over East Asia to represent China precipitation. In accordance, we calculated the correlation coefficient between the Asian $T'$ index and the CECP index. The corresponding values are 0.43 and 0.38, respectively before and after detrending, which are less correlated than when correlating the APO and CECP indices. Therefore, the APO, which embodies the Asian–Pacific zonal difference of the tropospheric temperature, seems to be a better index for indicating the rainfall anomalies over central eastern China.

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