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The interdecadal trend and shift of dry/wet over the central part of North China and their relationship to the Pacific Decadal Oscillation (PDO)

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Based on monthly precipitation and monthly mean surface air temperature (SAT), the dry/wet trends and shift of the central part of North China and their relationship to the Pacific Decadal Oscillation (PDO) from 1951 to 2005 have been analyzed through calculating surface wetness index (SWI). The results indicate that there was a prominent drying trend and an abrupt change in the analysis period. A persistent warming period with less precipitation from the mid and late 1970s to present was found, and a shift process exists from the wet to the dry in the central part of North China during 1951—2005. The transition is located in the mid to late 1970s, which should be related to the shift variation of large-scale climate background. The correlation analysis has brought about a finding of significant correlativity between PDO index (PDOI) and SAT, precipitation and SWI in this region. The correlation exhibits that the positive phase of PDOI (warm PDO phase) matches warming, less precipitation and the drought period, and the negative PDOI phase corresponds to low SAT, more precipitation and the wet period. The duration of various phases is more than 25 years. The decadal variation of sea surface temperature (SST) in the North Pacific Ocean is one of the possible causes in forming the decadal dry/wet trend and shift of the central part of North China.

North China, dry/wet trends, Pacific Decadal Oscillation, correlation

1 Introduction

As one of serious natural disasters in the world, drought has been paid much attention to by scientists and the public. The loss of life and economy damage are increasing due to drought, thus the shortage of water resources has become a bottleneck in the development of regional economy. The central part of North China, a fast economic developing region of China, is facing a severe problem of the shortage of water resources, which can be mainly attributed to the precipitation decrease from the mid and late 1970s. The latest warming makes it worse for the water resources in this region. The persistent drought for about 30 years is the marked problem to limit the social and economic development. The deep understanding about these problems will help us to reasonably utilize water resource, and provide some proof for the development of regional economy and society.

In the 1930s, Zhu[1] studied the natural disasters related to drought in the central part of North China, but the systematic explorations on drought problems, including rules and forming mechanism, started in the mid 1980s. The previous studies have provided a number of facts about the drought in the central part of North China[2−4], which will present much useful evidence from the perspective of climatic change to explore the

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mechanism of drought in this region. Recently, warming impacts on the forming and evolution of drought have been noticed by many researchers, and facts of the increase in the drought intensity and drying trend due to warming have been revealed at global and regional scales[5−7]. Many studies show that only analysis of precipitation variation cannot objectively depict the extent and intensity of drought and drying trend under warming, especially in the climate background of decreasing precipitation and increasing SAT. The warming has already become one of important factors enhancing drought and drying trend[5,8]. Consequently, the objective representation of drought and drying trend should consider both impacts of precipitation and SAT variation.

The objective representation of drought and drying trend is a difficult problem for researches and applications, and its nature is the shortage of water and the decreasing trend. The objective description of the water shortage needs to calculate the water budget of land-air system, and the analysis of considering only precipitation cannot satisfy the intention. In 1965, Palmer[9] suggested a drought index (hereafter cited as Palmer index) based on the concept of surface water balance, and this index is widely used in detecting and analyzing the drought and drying trend at global and regional scales. But the limitation of the calculating scheme of Palmer Drought Severity Index (PDSI) is that there are many parameters needed, which cannot be obtained from observation at present, so some parameters, such as soil moisture especially in long term and at large scale, induce the uncertainties in calculating PDSI. In order to avoid the limitation of PDSI, other drought indices were adopted for the analysis of drought and drying trend at regional scale[5,10,11]. For example, surface wetness index (SWI) was adopted to analyze the drying trend and its mechanism over North China. It reveals the important fact that the dry trend of northern China is enhanced in the last half century. This shows that the index is a reasonable tool to detect aridification and study the impacts of warming on forming processes of drought[12].

As for the forming mechanism of drought, previous studies explored it widely at various time scales. Xu et al.[13] indicated that a decadal abrupt change of precipitation decrease in the late 1970s was consistent with the jump of atmospheric circulation, and this abrupt change disperses from surface to the upper troposphere. Zhang et al.[14] found that the continuous less precipitation over the central part of North China since the 1980s corresponds to the variation of the summer vector wind anomalies and the enhanced west wind circulation in the middle latitude of Asia, but the south wind of vector wind anomalies of 850 hPa from 110°E to 120°E is weaker than that of mean climate state. The persistent drought above 30 years in the central part of North China is related to the weak summer monsoon of this region[15] and the decrease of water vapor transported northward by the summer monsoon of East Asia[16]. Except for the atmospheric circulation, SST variation of middle and low latitudes over the Pacific Ocean is closely related to precipitation variability in the central part of North China[17−20]. In addition, carbon dioxide[21] and the thermodynamic state of Tibetan Plateau[22] have important impacts on drought and precipitation variation during flood season in the region.

At decadal scale, SST change is important for the formation of drought in the central part of North China. The variation of precipitation and temperature of the central part of North China was consistent with the PDO, and the warm phase corresponds to the period of less precipitation and increasing temperature[17,23]. Yang et al.[19] studied their linkage to abnormal thermodynamic structure of SST in the Pacific Ocean. Consequently, the decadal variability of climate in the central part of North China is closely related to the decadal variation of SST in the Pacific Ocean. However, what is the effect of less precipitation and increasing temperature corresponding to PDO warm phase at present on the extent and intensity of drought of the central part of North China? What is integrated characteristic of climate variation affected by it? And how is it related to PDO? The answers to above questions will help us to understand deeply the characteristics and mechanism of current continuous drought in the central part of North China.

Enlightened by previous studies, we analyzed the relationship between the dry-wet variation in northern China and PDO[23]. The result shows a significant correlation between the dry-wet variation and PDO in this region, and larger correlation coefficients are located in the central part of North China, the eastern part of northwestern China and the southern part of Tianshan Mountains, respectively. The significant negative correlation between them exists in the eastern part of North China (including the central part of North China and the eastern part of northwestern China). Especially in the central part of North China, there is always a significant correlation (passing the significance level of 95%) during 1—10 years with SWI lagging PDO[23]. Though the study above shows the relationship between the dry-wet variation of environment and large-scale climate background, the comparison of relationship between the dry-wet variation at various time scales and PDO is still lacking, and the relationship between seasonal change of PDO and dry-wet variation is not clear. Consequently, the problems above need to study deeply. In regard to the above problems, we will use the SWI to analyze the correlation coefficients between PDO and decadal trend of dry-wet variation in the central part of North China, to compare the dry-wet variation at various time scales to PDO and to explore seasonal characteristics of the correlation between PDO and the dry/wet variation.

2 Data and methods

The 1951—2005 data of monthly precipitation and monthly mean temperature of 160 stations are from China Meteorological Administration. According to the previous study and ref. [20], the range of the central part of North China is a rectangle located between 35—42.5°N, and 110—117.5°E, which includes 15 stations of Zhurihe, Duolun, Zhangjiakou, Hohhot, Beijing, Tianjin, Shijiazhuang, Dezhou, Xingtai, Anyang, Jinan, Heze, Changzhi, Taiyuan and Linfen. Monthly index of PDO is taken from the website http://jisao.washington.edu/pdo/PDO.latest[24], abbreviated as PDOI, and annual PDOI is the arithmetic mean of 12-month PDOI.

The surface wetness index (SWI) is calculated through monthly precipitation and monthly mean temperature, and the equation of SWI is

$$SWI = \frac{P}{P_e}, \tag{1}$$

where P is observed annual precipitation, P_e is annual potential evaporation calculated by sum of month-to-month potential evaporation. Monthly potential evaporation was calculated using Thomthwaite[25] scheme, which is detailed in ref. [23].

Mann-Kendall (MK) method[26] was adopted to detect the trend and abrupt change of the dry-wet variation. When the absolute value of MK test is greater than 1.96, the trend is significant (passing the significance level of 95%). The positive value means increasing trend, and the negative value represents decreasing trend.

3 Results

3.1 The trend of dry-wet variation in the central part of North China

In the central North China, multi-year averaged annual precipitation (from 1961 to 1990) was 503 mm, and annual mean SAT is 10.5℃, belonging to a typical semi-arid region. From 1951 to 2005, there was a linearly decreasing trend of annual precipitation at the rate of 14.2 mm/10 a, and a linearly increasing trend of annual mean SAT of 0.35℃/10 a, which accounted for a warming and less precipitation climate. Before analyzing the decadal characteristics in the central part of North China, we present the trend of decadal dry-wet variation from 1951 to 2005 over China. Using formula (1), annual SWI was calculated in each station of this region. In order to highlight the decadal trend of dry-wet variation, a 9-year running mean of annual SWI was implemented, and then trends of dry-wet variation in each station were calculated by MK method. Finally, the spatial distributions of trends of dry-wet decadal variation are shown in Figure 1. We can find that a drying trend dominates in east of 100°E and north of 35°N, and the most marked drying trends are located in the eastern part of northwestern China, the central part of North China, the central and southeastern parts of Northeast China, respectively. But a wetting trend dominates in the western part to 100°E, the completely reverse trend exits between eastern and western part along 100°E, and the reason for this spatial distribution is not clear.

Though we found the close correlation between PDOI and decadal dry-wet change in the central part of North China[23], a systematic analysis is needed to understand deeply their relationship and possible mechanisms. In order to give clearly the decadal characteristics of dry-wet variation in the central part of North China, a regional mean SWI of 15 stations was implemented, and a 9-year running mean for the regional SWI and precipitation series was also implemented. The anomalies relative to the period from 1961 to 1990 were calculated, the comparison of the anomalies to 9-year running mean PDOI was made to study their relationship at decadal scale.

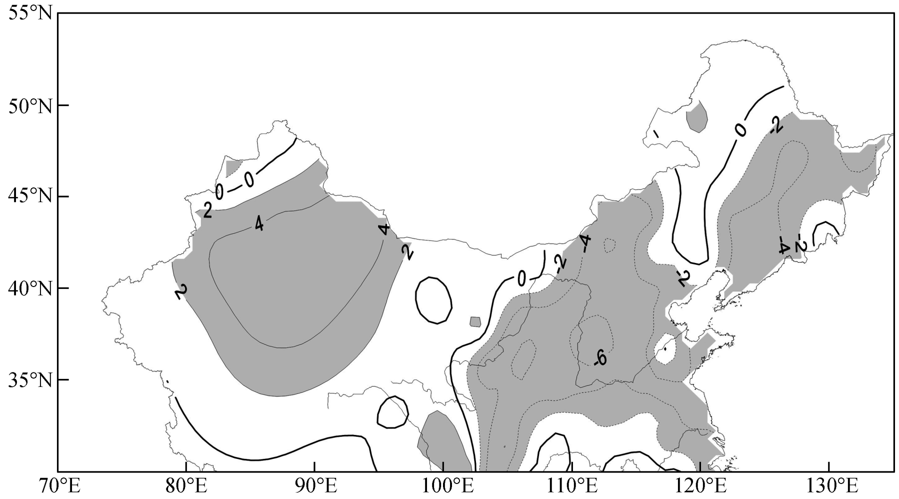

Figure 1 The trend of dry/wet variation in China from 1951 to 2005 (MK method). Dash line means regions with drying trend, solid line refers to regions with wetting trend.

3.2 The characteristic of abrupt dry-wet variation in the central part of North China and its relationship to PDOI

Figure 2 shows variations of 9-year running mean annual and spring PDOI, regional mean anomalies of 9-year running-averaged annual precipitation, SAT and SWI in the central part of North China. We found that there is a significant decadal shift characteristic of annual precipitation, SWI, annual and spring PDOI. Before 1976, negative SAT anomalies of cold period continue for 25 years, and positive SAT anomalies of warm period after 1976 persist for about 30 years. Simultaneously, there exists a shift variation of annual precipitation anomalies from positive to negative after the middle to late 1970s. Except for 1992 and 1994, the anomalies of annual precipitation were negative in other years, and it is a phase of less precipitation. The SWI has a shift characteristic similar to annual precipitation, from positive to negative after the middle to late 1970s, and it is a prominent drought lasting for about 25 years. The shift may be related to the 50—70 years decadal oscillation of climate[27] over the North Pacific and North America. The variations of spring and annual PDOI show an obvious shift from cold to warm phase in recent 55 years (Figure 2 (d) and Figure 2 (e)), and the cold phase before 1977 has persisted for about 25—30 years. The latest warm phase has persisted for above 25 years since 1978. We also found that the warm phase of PDOI matches high SAT (warming), less precipitation and drought period, and the cold phase of PDOI corresponds to low SAT (cold), more precipitation and wetness through the comparisons of annual and spring PDOI to precipitation, SAT and SWI anomalies. If the switch point of anomalies sign is defined as a shift time, the negative to positive shift of annual and spring PDOI is during 1976/1977, one year later than that of SAT. The shift of precipitation and SWI anomalies from positive to negative is during 1977/1978, one year later than that of PDOI. In order to validate whether the shift time changes with time scale of running mean or not, we analyze the shift time of SWI variation in 5-year, 7-year and 9-year running mean, respectively. The corresponding shift time is 1978/1979, 1977/1978 and 1978/1979, respectively. So, the shift time (the reverse sign of SWI anomalies) slightly varies with the time scale of running mean, we cannot determine exactly the shift time only according to the variation of a 9-years running mean series. But the facts above present two valuable messages at least: One is a shift variation of SWI in the mid to late 1970s, which is consistent with the shift variation of global climate, the other is that the shift time of precipitation and SWI lags 1 year compared with that of PDOI except SAT. Consequently, does PDO induce shift change of other climate variables? What is the linked mechanism between SAT and PDO? So far these are unknown yet. The central part of North China is in the northern end of East summer monsoon, and the precipitation variation is markedly influenced by the intensity variation of East Asian summer monsoon. The intensity of summer monsoon is closely related to the thermodynamics discrepancy between East Asia continent and the Pacific Ocean. However, the warm phase of PDO lasting

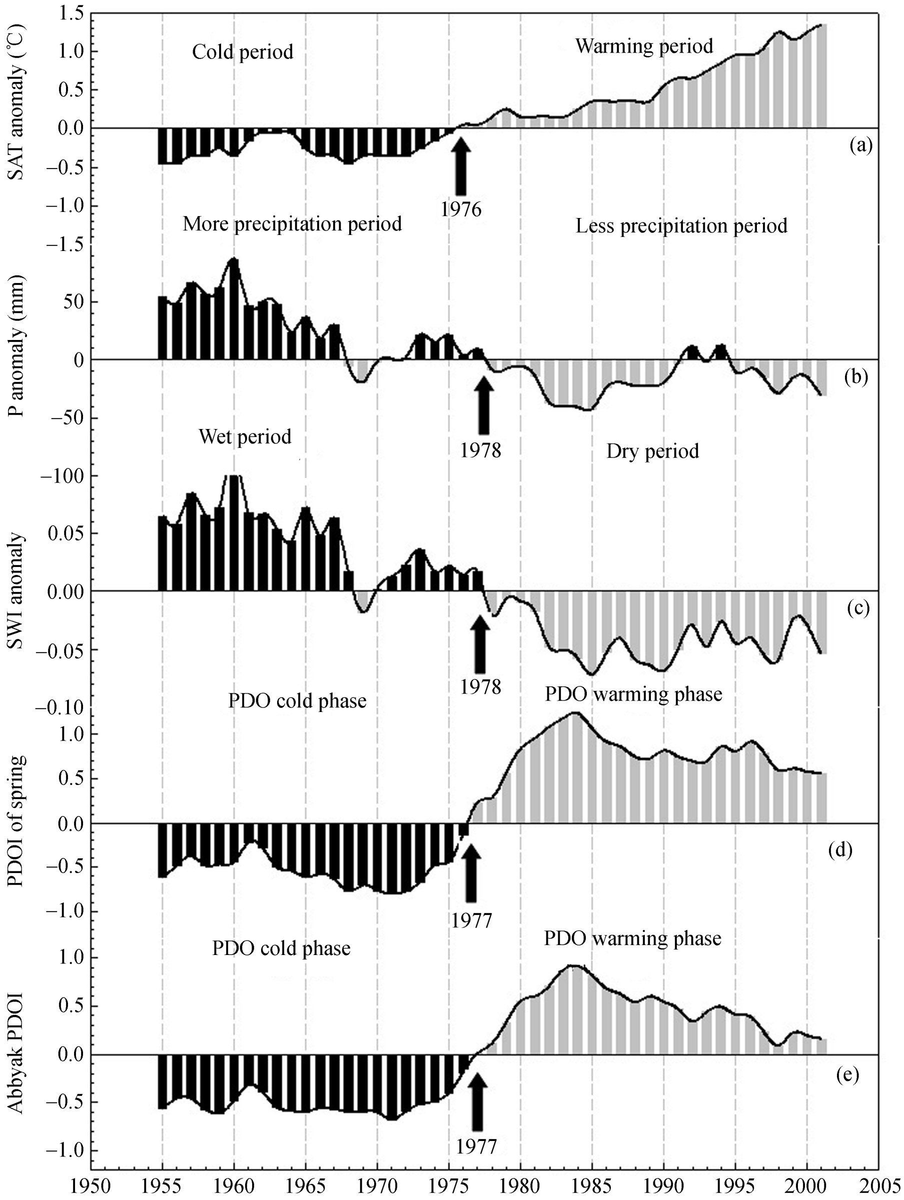

Figure 2 Regional mean variation of (a) SAT anomaly, (b) precipitation anomaly, (c) SWI anomaly, (d) spring PDOI, (e) annual PDOI in North China.

for more than 20 years occurs with a cool SST over the northwestern and central Pacific. The cool SST in these regions leads to larger thermodynamics discrepancy between the continent and ocean in summer, So what is the relationship between the larger discrepancy and the weaker East Asian summer monsoon after the mid to late 1970s? The answer to the issue is a key project in studying the forming mechanism of drought in the central North China.

Compared precipitation to SWI in the central part of North China (Figure 2 (b) and (c)), the whole trend of precipitation variation in the central part of North China is decreasing. From 1991 to 1995, the anomalies of annual precipitation are positive, but there was a little increase of precipitation (Figure 2 (b)). Figure 2(c) is accompanied with drought due to persistent warming in these years. This accounts for that a little more precipitation cannot alter the drought status because of increasing SAT, which is an important evidence of drought enhanced by warming. The comparisons of the phase of SWI and precipitation to PDOI phase show that PDO seems a factor to drive the decadal character of the dry-wet variation in the central part of North China. However, which physical process of the driven power affects the decadal oscillation of dry-wet variation in northern China? At present, as one of driven factors of decadal climate, its forming cause of PDO is still not clear[24].

In order to understand deeply the relationship between PDO and dry-wet variation, the correlation coefficients between regional mean SAT, precipitation, SWI and seasonal and annual PDOI were analyzed, respectively. Table 1 shows the correlation coefficients of non-running mean (N1 series), 5-year running mean (N2 series) 9-year running mean(N3 series) SAT, precipitation and SWI with PDOI of four seasons (PDOI 1, PDOI 2, PDOI 3, PDOI 4), and with annual PDOI (PDOI 5). Table 1 shows that there is significant positive correlation between SAT and winter, spring, and annual PDOI at interannual scale (N1 series), where the correlation coefficient between annual SAT and spring PDOI is 0.46 and passes the significance level of 99.9%. The positive correlation exists in between annual SAT and summer PDOI, but it can not pass the significance level of 95%. The correlation coefficient of annual SAT with autumn PDOI has the least value of –0.06. However, different from the correlation between SAT and PDOI, the correlation of non-running mean precipitation with seasonal and annual PDOI can not pass the significance level of 95%. From the analysis above, PDO is only closely related to SAT at interannual scale in winter and spring, especially in spring with the largest correlation coefficient. For the 5-year time scale (N2 series), except in autumn, the correlation of annual SAT, precipitation and SWI with PDOIs in other three seasons reaches the significant level of 99.9%. This result indicates the close correlation of PDOI with annual SAT, precipitation and SWI at above 5-year time scale. The significant positive correlation exists between annual SAT and PDOI, and a significant negative correlation between annual precipitation, SWI and PDOI occurs. In other words, the warm (cool) phase matches the high (low) SAT, less (much) precipitation and large (little) SWI. At decadal scale (N3 series), the correlation is similar to that of N2 series with exception that the correlation coefficient becomes larger and the correlation is much more significant. The correlation coefficient between annual PDOI and annual SWI is –0.83. We also found that the correlation coefficient between PDOI and SWI is larger than that between precipitation and PDOI for N3. This means that if we consider the integrated effect of climate, the variation of PDOI and SWI is much more consistent with that of PDOI and precipitation, so PDOI may be taken as a prediction index of SWI variation at decadal scale. We conclude that the correlation between PDOI and climate change at interannual time scale can be represented only by the correlation between PDOI and annual SAT, and at above 5-year time scale, there are strong correlation between annual or seasonal PDOI with SAT, precipitation and SWI, respectively. The relationship of the comprehensive effect of climate variable (such as SWI) with PDO is closer than that of single climate variable with PDO.

Table 2 shows the correlation coefficient of the first 5 components of SWI derived from Empirical Orthogonal Function (EOF) with seasonal and annual PDOI. In table 2, there is a significant negative correlation of PDOIs with the 5 principal components of SWI in central North China, especially for the first and second principal components with correlation coefficients passing the significance level of 99.9%, and the correlation coefficients of other principal components with PDOIs reach the significant level of 95%. Compared to other four principal components, the correlation of the fourth principal component with PDOI is the weakest. The variance sum of the first and second principal components contributes to 77% of the total variance, and the variance sum of the first five principal components accounts for 95% of total variance. Therefore, the variation of the first five principal components can represent the overall

Table 1 The correlation coefficient of PDOI with regional mean temperature, precipitation and SWI at various time scales

	Annual SAT			Annual precipitation			Annual SWI		
	N1	N2	N3	N1	N2	N3	N1	N2	N3
PDOI 1	0.41^{**}	0.52***	0.62***	–0.00	–0.56***	–0.71***	0.17	–0.58***	–0.76***
PDOI 2	0.46^{***}	0.63***	0.75***	–0.19	–0.56***	–0.69***	0.05	–0.66***	–0.82***
PDOI 3	0.24	0.50***	0.70***	–0.19	–0.48***	–0.65***	0.05	–0.62***	–0.82***
PDOI 4	–0.06	0.24	0.38**	–0.24	–0.56***	–0.73***	–0.12	–0.60***	–0.77***
PDOI 5	0.29^{*}	0.53***	0.66***	–0.22	–0.58***	–0.72***	0.01	–0.66***	–0.83***

PDOI 1 means index of PDO in winter, PDOI 2 in spring, PDOI 3 in summer, PDOI 4 in autumn, and PDOI 5 is annual index of PDO; N1 is non-running mean series, N2 is 5-year running mean, and N3 is 9-year running mean. ∗, Correlation coefficient passes significant level of 95%; ∗∗, the passing significance level of 99%; ∗∗∗, the passing significance level of 99‰.

Table 2 Correlation of 9-year running mean PDOI with principal components trend of SWI by EOF in central North China

	PCA1	PCA2	PCA3	PCA4	PCA5
PDOI 1	-0.555^{***}	-0.764^{***}	-0.611^{***}	-0.313^{*}	-0.556^{***}
PDOI 2	-0.523^{***}	-0.851^{***}	-0.665^{***}	-0.426^{**}	-0.657^{***}
PDOI 3	-0.511^{***}	-0.876^{***}	-0.575^{***}	-0.367^{*}	-0.652^{***}
PDOI 4	-0.578^{***}	-0.817^{***}	-0.348^{*}	-0.409^{**}	-0.397^{**}
PDOI 5	-0.561^{***}	-0.866^{***}	-0.591^{***}	-0.401^{**}	-0.606^{***}

PCA1-PCA5 are the first to fifth principal components of SWI; others are the same as in Table 1.

characteristics of the variation trend at decadal scale in recent 55 years. Figure 3 shows the variation of temporal coefficients, linear trend (left figure) and detection of abrupt change (right figure) of the first five principal components. The decadal linear trend of temporal coefficients of the first five principal components decreases in recent 55 years, which indicates a general drying trend in this region from 1951 to 2005 (right of Figure 3). The detection for trend and shift point of SWI also shows a significant drying trend by using MK method (MK test value is less than or equal to −1.96. A significant drying trend exists in the first principal component without jump variation (no cross points between curve lines C_1 and C_2)[26]. The trend of the third and fourth principal components is similar to that of first principal component, having a significant drying trend and no jump variation. A shift point can be found in the variation of temporal coefficients of the second and fifth principal components. The shift point of PCA2 is in 1976/1977, and that of PCA5 in 1979/1980. From the results above, we can conclude that there exists a significant drying trend and jump variation from wet to dry period, which occurred in the middle to late 1970s. The shift variation of PCA2 in 1976/1977 matches that of SST over the central Pacific, northern Pacific[28,29] and tropical Pacific as well as the climate shift over these regions[30,31]. But we can not conclude that the shift variation of SWI in the central North China is attributed to the shift variation of SST over the Pacific Ocean. As mentioned above, precipitation in the central North China, one of the key factors causing dry-wet variation, is significantly affected by the variation of East Asian monsoon. In 1976/1977, the SST over the central and northern Pacific Ocean shifts from positive anomaly (warming) to negative anomaly (cold)[28], but the contrary shift exists over the tropical Pacific. This would cause the temperature difference to increase between

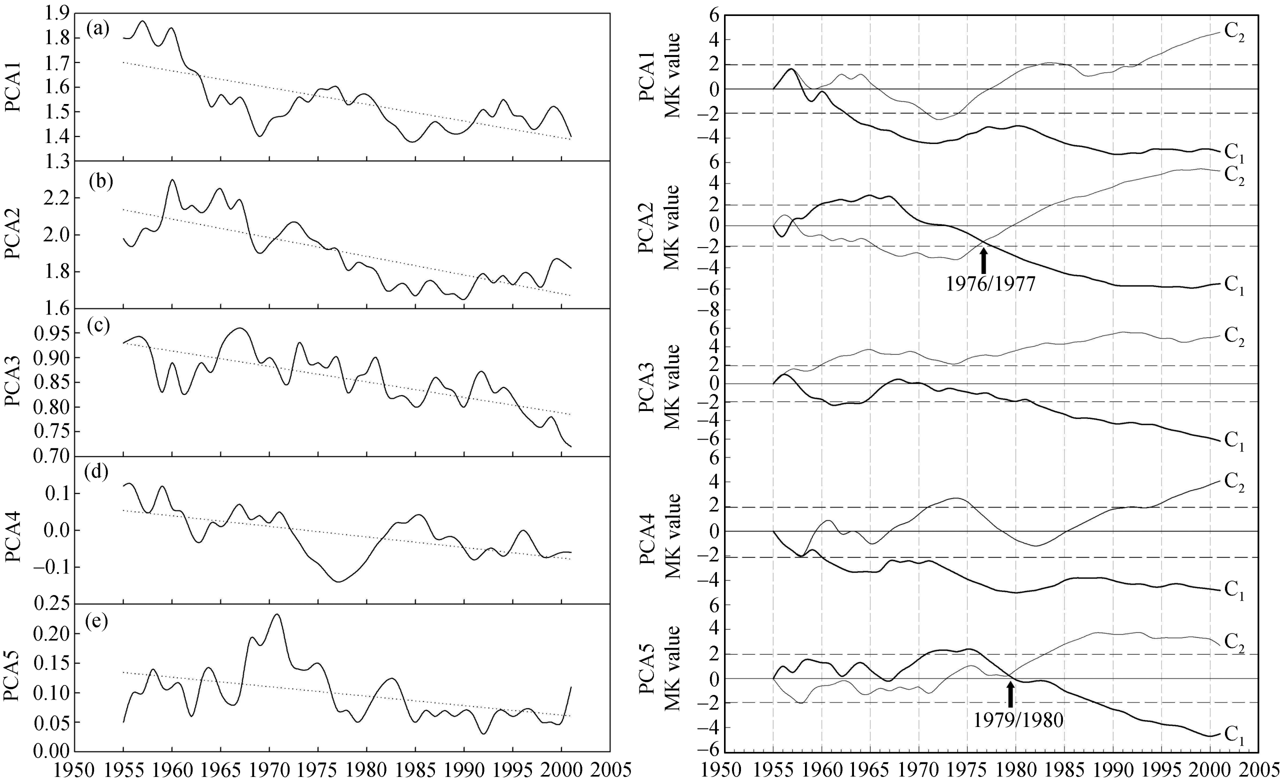

Figure 3 The variation and linear trend of (a) the first, (b) second, (c) third, (d) fourth and (e) fifth principal componenst (left); and the jump detection of each principal component by MK method (right). The cross point of C_1 and C_2 located between −1.96 and 1.96 is the jump point.

land and ocean in middle and high latitudes, and to decrease in low latitude and the equator. However, it is not clear how the different temperatures between land and ocean contribute to the present weakened East Asian summer monsoon, and the mechanism needs to study in the land-air-ocean coupled model.

From the analysis above, it can be seen that there is a significant drying trend with the duration of above 25 years in the central North China after the middle 1970s, and a wetting trend of more than 25 years existed before this period. At interannual scale, only annual mean surface air temperature (SAT) has significant correlation with winter and spring PDOIs. At 5-year scale or larger, the significant correlation of SAT, precipitation and SWI with various seasonal and annual PDOIs can be found. The warm phase of PDO corresponds to the continuous high SAT, less annual precipitation and drought period, and the cold phase matches the low SAT, rainy and wetness periods. If PDO is taken in to account as an important factor influencing climate and environment change in the central North China, the linkage mechanism between the decadal dry-wet changes of climate and environment and that of SST anomaly is still unknown.

4 Discussions

With regard to the causes of PDO occurrence, there are three sides[32]: 1) the interaction between tropical and sub-tropical regions[33 – 35]; 2) from the processes in tropical regions[36,37]; 3) the processes over mid to high latitudes[38,39]. Its forming mechanism has been argued up to now[24,40], and the focus of controversy is the source region of PDO. In other words, the occurrence of PDO is from the result of land-sea interaction over the Central and North Pacific Ocean or from the influence of the atmospheric teleconnection over the tropical Pacific[40]. These issues should be studied by coupled climate models and diagnostic analysis with more perfect observation data. Simultaneously, the mechanism of PDO's influence on decadal climate change in the central North China is not clear, but many facts for the physical evidence of the close linkage between PDO and the climate change in central North China have been found. When the period of less precipitation occurs in the central North China, PDO has a warm phase, and more precipitation matches the cold phase of PDO[19−23]. Summer sea level pressure (SLP) in mid-high latitudes of East Asia is obviously high during 1977 to 2000 compared with the period 1960 to 1976. The synchronous weak monsoon exists in East Asia, resulting in a reduction of northward vapor transport. The increasing trend of summer SLP implies the weakened Indian low pressure controlling the monsoon intensity in East Asia, and this circulation background is not advantageous to precipitation production in the central North China, so the high surface air temperature and less precipitation occur[41]. As for the warm phase of PDO, the SST anomaly is very low in the central and northwestern Pacific and very high in the northeastern Pacific (western coast of North America)[24]. The temperature difference is enhanced between low SST over the central and north Pacific and high temperature in East Asian continent, and how does the increased difference affect the variation of East Asian summer monsoon? What is the relationship between the large difference of low SST and high land temperature in mid-high latitudes? These issues are unclear. As mentioned above, the East Asian monsoon is a key factor affecting precipitation in the central North China, and its basic forming mechanism is the large temperature difference between the continent of East Asia and the Pacific Ocean. The warm phase of PDO depicts the low SST in the central and northwest Pacific, and the temperature difference affecting East Asian monsoon in low latitude of East Asia should be considered. According to basic forming mechanism of monsoon, the present weak monsoon of East Asia should correspond to a decreasing trend of temperature difference between land and ocean in low-mid latitudes. This is opposite to the increasing trend of land-ocean temperature difference in high latitudes (the region of the central and northwest Pacific), and the relative contributions of these opposite trends of land-ocean temperature difference to present weakened East Asia summer monsoon and the relationship between them are hardly studied. From the perspective above, it is necessary to study deeply the linkage mechanism between the decadal SST variations in mid-high latitudes and low latitudes, and the effect of thermodynamic difference contrast in different latitudes in order to better understand the mechanism of PDO's influence on the dry-wet variation in the central North China.

5 Summary

The results in this study show a overall significant drying trend with climate status of warming and less precipitation in the central and North China from 1951 to 2005. At decadal time scale, the whole variation in this region is high temperature (increasing trend of SAT), less precipitation (decreasing trend of precipitation) and drought (decreasing trend of SWI) at recent. This phenomenon has continued since the mid-late 1970s, covering about 30 years. If the sign of anomaly for a variable is taken as a standard definition of the shift variation, the shift point from low to high surface air temperature (SAT) is in 1976 from 1951 to 1955, and the durations of low- and high-temperature are 26 years and 29 years, respectively. The precipitation shifts from more to less, and the shift point is in 1977/1978. Then a continuous drought with high SAT and less precipitation has occurred since 1977/1978. The transition characteristic of various variables in the central North China is possibly related to the 50—70 years oscillation of climate over the northern Pacific Ocean[32].

The correlation analysis presents the close relationship between PDOI and regional mean surface air temperature (SAT), precipitation and SWI in central North China. The warm phase of PDO (positive PDOI) matches high SAT, less precipitation and the drying trend, and the cold phase corresponds to low SAT, more precipitation and the wetting trend. The recent warm phase of PDO started in 1977, one year later than the warming period (positive anomaly of SAT) and one year earlier than the decreases of precipitation and SWI. The phase differences of the shift point of the above variables perhaps vary with the definition of shift variation, but it is undoubted that the shift points of all variables occurred in the mid-late 1970s. Also, we can find linear decrease trend of the first five principal components of SWI by EOF method in the central North China, and this means an overall significant drying trend in this region in recent 55 years. A significant simultaneous correlation between annual, seasonal PDOIs and the first five principal components can be obtained, and the correlation coefficient reaches the significance level of 99.9%. The detection analysis of EOF shows that the jump change of time coefficients of the second and fifth principal components occurred in 1976/1977 and 1979/1980, respectively, and it is a trend varying from the wet to dry.

These results above indicate that the climate and the dry-wet status have obvious characteristics of decadal trend and jump change, and they are significantly related to PDO at decadal scale. The linkage mechanism between them cannot be reasonably depicted under the unclear background of forming cause of PDO. This will be an important scientific issue which needs to study deeply in exploring the decadal dry-wet change of climate and environment in the central North China in future, and the understanding of it will be helpful to predicting decadal dry-wet change of environment in the region.

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