A Review of Decadal/Interdecadal Climate Variation Studies in China

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ABSTRACT

Decadal/interdecadal climate variability is an important element in the CLIVAR (Climate Variability and Predictability) and has received much attention in the world. Many studies in relation to interdecadal variation have also been completed by Chinese scientists in recent years. In this paper, an introduction in outline for interdecadal climate variation research in China is presented. The content includes the features of interdecadal climate variability in China, global warming and interdecadal temperature variability, the NAO (the North Atlantic Oscillation)/NPO (the North Pacific Oscillation) and interdecadal climate variation in China, the interdecadal variation of the East Asian monsoon, the interdecadal mode of SSTA (Sea Surface Temperature Anomaly) in the North Pacific and its climate impact, and abrupt change feature of the climate.

Key words: decadal/interdecadal climate variation, abrupt change, east-Asian monsoon, sea surface temperature anomaly

1. Introduction

In the 1990s, the research on interdecadal variation originally focused on the oceanic state, because the oceanic variability was thought to be a slower process and its interdecadal features more evident. Some studies have shown that the sea surface temperature (SST) variation in the North Atlantic Ocean has a clear interdecadal character and it is related with the NAO (the North Atlantic Oscillation) (Bacon and Carter, 1993; Hurrell, 1995). In the Pacific Ocean, interdecadal variation of the ENSO has been studied (Wang, 1995; Qian et al., 1998) and the EOF analysis of SST in the North Pacific still shows an interdecadal variation feature. In the EOF analyses, the primary part of the main EOF components, which is similar with the ENSO variation, was regarded as the representative of interannual variation (Tanimoto et al., 1993); the remaining part of the main EOF components, which is similar to the ENSO mode, was regarded as the interdecadal variation and named the "ENSO-like mode" (Zhang et al., 1997) or the Pacific Decadal Oscillation (PDO) (Mantua et al., 1997). The studies also indicated the existence of interdecadal variation in the North Pacific with other data analyses (Trenberth and Hurrelle, 1994; Li and Liao, 1996; Li, 1998) and it was still clear in the thermocline variation (Zhang and Levitus, 1997). Naturally, the interdecadal variability of the North Pacific SST and its impact on the climate became important parts of the international CLIVAR (A study of Climate Variability and Predictability) program (WMO et al., 1995). The studies also indicated that the interdecadal climate variation is still shown in the atmospheric circulation variability (Li and Li, 1999a; Li, 2000).

In fact, interdecadal climate variation in China and its jump feature have been studied early. The drought and flood variations in China, and the long-term variations of the summer rainfall and surface temperature in China have been studied and some interesting results were found (Wang and Zhao, 1979; Wang et al., 1981; Wang, 1990; Jiang et al., 1999; Huang et al., 1999; Chen, 1999; Lu, 1999). Some studies and major results in recent years will be shown in this paper in

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broad outline, and we regret that it is hard to avoid the omission of some studies.

2. Features of interdecadal climate variation in China

Some studies have shown that there is a clear interdecadal variability of summer rainfall over eastern China during the second half of the 20th century (Zhao, 1999; Wang, 2001). Power spectrum analyses for summer rainfall showed a significant peak at 26.7 years. A decreasing trend in precipitation variations has been found based on the observations since 1951, and it seems to end in the 1980s. A weak increasing trend was observed in the 1990s, but their characteristics were different for different areas in China. It is shown that summer rainfall over eastern China, especially over North China, is above normal during the 1950s. Rainfall was slightly above normal north of the Huaihe River and drought occurred along the lower–middle Yangtze River basin and South China during the 1970s. The floods occurred along the Yangtze River basin and droughts were predominant in South and North China during the 1980s. In the 1990s, summer rainfall was above normal along the Yangtze River basin and South China. At the same time, North China was still facing a prolonged drought period.

The characteristics of interdecadal variability of annual precipitation are similar to those of summer rainfall over eastern China. There have been five drought spells since 1880. The first one was from the end of the 19th century to the beginning of the 20th century, the second from the second half of the 1920s to the beginning of the 1930s, the third and the fourth for the whole period of the 1940s and 1960s, and the fifth from the end of the 1970s to the beginning of the 1980s. No linear trend occurred during the period from 1880 to 1999. The power spectrum analysis shows a significant peak around 30 years. A 20–40-yr periodicity is predominant for the whole series. The anomalies relative to the period of 1880–1999 for 6 flood and 5 drought spells are shown in Table 1.

The studies on summer rainfall in North China showed that the interdecadal variation is also evident (Chen, 1999; Huang et al., 1999; Li et al., 2002). The major variation periods are about 20 years and about 40 years. It was indicated that these interdecadal variations of summer precipitation are related to the anomalies of the intensity of the East Asian summer monsoon and the latitude of the subtropical high ridge over the west Pacific in summer (Fig. 1). For the strong (weak) East Asian summer monsoon period, there is abundant (sparse) rainfall in North China and for the north (south) side of the subtropical high ridge over the west Pacific in summer, there is abundant (sparse) rainfall in North China.

Precipitation variation is quite different for eastern China and western China. There was no linear trend during 1880–1999 and a 20–40-yr period variation was predominant for the whole series of eastern China precipitation. On the contrary, the increasing trend of precipitation in west China was very noticeable in the second half century, especially during the last 30 years. It also showed tremendous drought in the 1920s–1930s in west China.

A decadal-centennial variability is studied based on rainfall coded-level data in 1470–1999 at 25 stations over the eastern part of China. The power spectrum analyses of 530 years of rainfall data demonstrate that an 80-yr oscillation exists in some areas of the eastern part of China and reaches the 95% significance level (Fig. 2). The 80-yr oscillation component of summer rainfall in North China even explains 27% of the variance in the low frequency band. This component of summer rainfall over North China, the lower–middle Yangtze River valley, and South China shows that the phase of this component over North China is precisely consistent with that over South China and out of phase with that along the lower–middle Yangtze River valley.

Table 1. The precipitation anomalies averaged for 35 stations relative to the period of 1880–1999 during 6 flood and 5 drought periods (Wang, 2001).

NO	Flood		Drought	
	Period	Anomaly (mm)	Period	Anomaly (mm)
1	1881–1885	42.2	1899–1902	–109.6
	1888–1892	72.0		
2	1911–1915	94.5	1925–1929	–75.5
	1918–1922	65.2		
3	1931–1935	45.7	1942–1946	–19.9
4	1950–1954	90.0	1963–1968	65.1
5	1972–1976	62.2	1978–1982	–30.4
6	1990–1994	43.2		

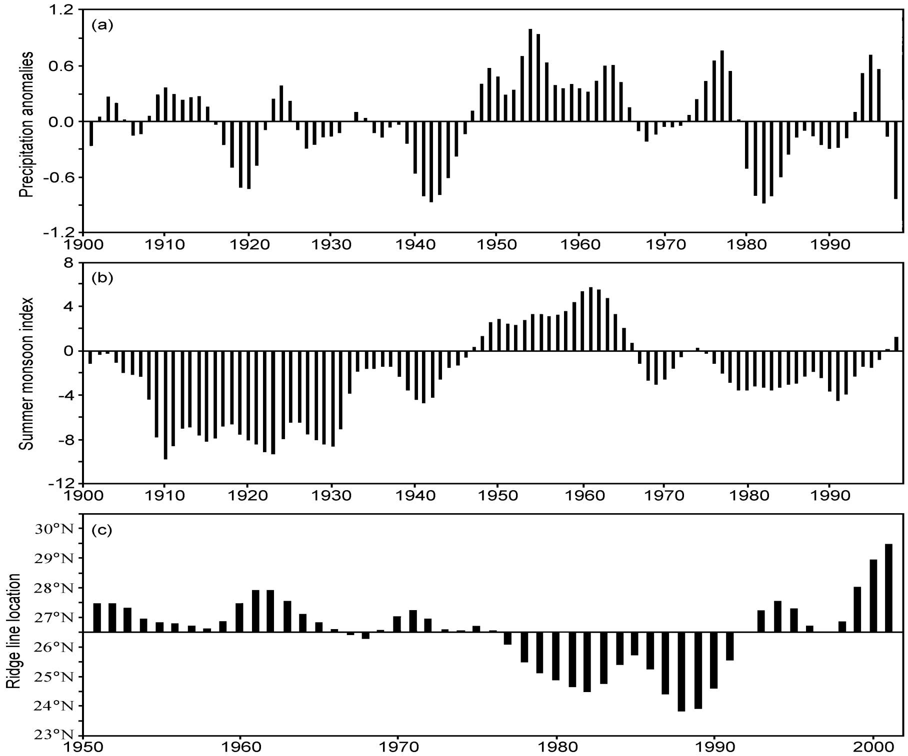

Fig. 1. (a) 9-year running mean histograms for the summer precipitation in North China, (b) the intensity of the East Asian summer monsoon, and (c) the latitude of the subtropical high ridge over the west Pacific in summer. (Li et al., 2002)

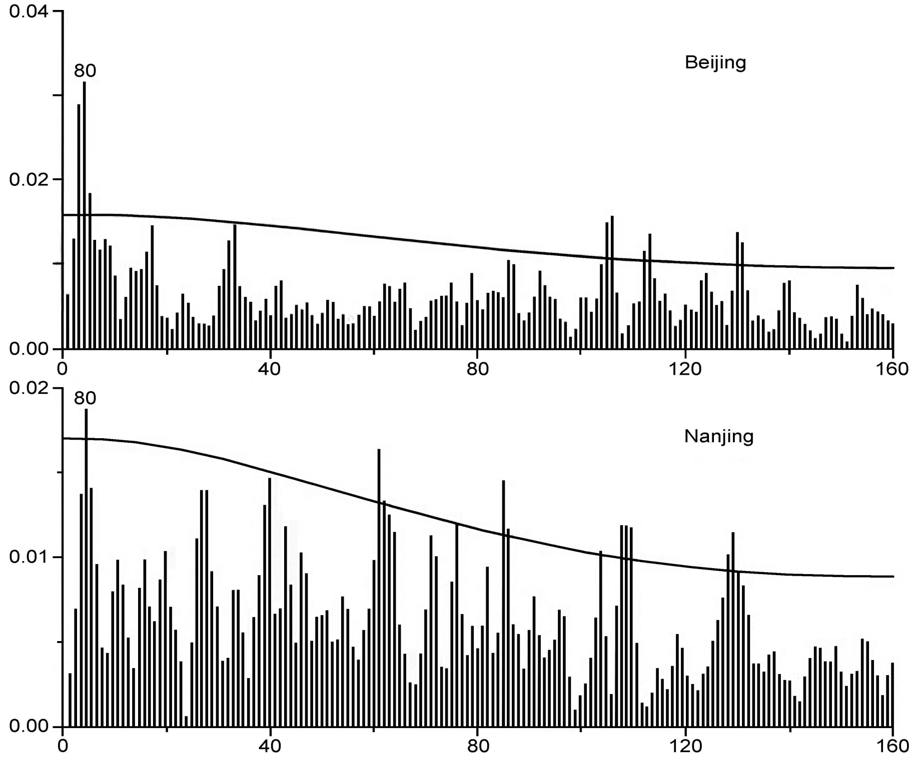

Fig. 2. Power spectra for the rainfall graded data (1470–1999) at Beijing and Nanjing. The solid line is the 95% significance level. (Zhu and Wang, 2001)

3. Interdecadal variations of the East Asian monsoon

The East Asian Summer Monsoon (EASM) is one of the important factors, which control summer rainfall over the east part of China. The rainfall in North China is also sensitive to the intensity of EASM. The subtropical high and ITCZ usually move to the north if the summer monsoon is strong and active, then the precipitation will be above normal over North and South China. In the opposite case, the subtropical High and ITCZ are displaced to the south when the summer monsoon is weaker, droughts will be found over North and South China, and floods will occur along the middle and lower reaches of the Yangtze River. The studies also showed that the EASM and summer rainfall over eastern China have variability features with multiple timescales, including interannual variation, decadal/interdecadal variation, and an 80-yr quasi-period oscillation (Zhang, 1999; Lu, 1999; Yang and Song, 1999; Zhu and Wang, 2001).

Li and He (2000) examined the correlation between the EASM and the SSTA over the China off-sea area, the western Pacific subtropical high ridge, and the equatorial eastern-central Pacific SST in the preceding winter and spring. The result showed that the relation between the EASM and equatorial eastern-central Pacific SST displays a strong interdecadal change, with a higher correlation after 1976 than before 1976. From the time evolution of the East-Asian summer meridional cell index, the zonal Walker cell index, and the equatorial eastern-central Pacific SSTA (Sea Surface Temperature Anomaly) in summer, it is clear that the coupling between the East-Asian summer meridional cell and zonal Walker cell exhibits an interdecadal change, although there is a stable, significant relation between the Walker cell and the equatorial eastern-central Pacific SSTA (Fig. 3). It is interesting to note that the negative correlation coefficients between the index of the East Asian summer meridional cell and zonal Walker cell is greater in magnitude than –0.77 in 1976–1993 at the 99.9% significance level, much higher in magnitude than that of –0.41 in 1958–1975. Therefore, after 1976 the warmer equatorial eastern-central Pacific SSTA leads to a weaker zonal Walker cell (weaker westerly flows in the upper troposphere and weaker easterlies in the lower one). These changes weaken the East Asian summer meridional cell (weaker northerly flows in the upper troposphere and weaker southerlies in the lower one) due to its close coupling with the zonal Walker cell, accompanied by the weaker summer monsoon and the southward shifting of the subtropical high, resulting in enhanced rainfall in the low-mid reaches of the Yangtze River.

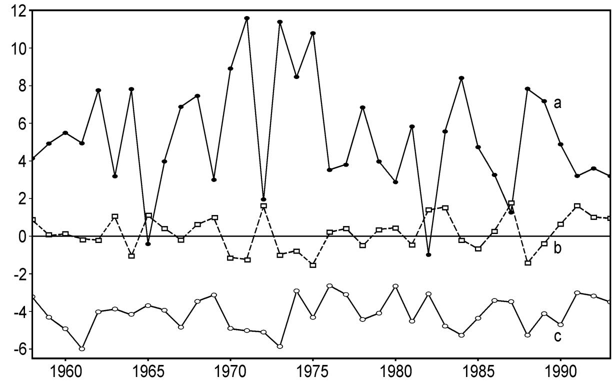

Fig. 3. Time evolution of the East-Asian summer meridional cell index (solid line c), zonal Walker cell index (solid line a), and the equatorial eastern-central Pacific SSTA in summer (dashed line b). (Li and He, 2000)

4. Global warming and interdecadal temperature variability

The annual mean temperature anomaly series of ten regions in China are studied and obtained for the period of 1880 to 1999, which are determined relative to the normals of 1961–1990 (Wang et al., 1998). The temperature series of China are averaged over ten regions considering the regional weights (figure omitted). It is indicated that the warming in the 20th century started in 1920 and was interrupted in the 1950s and 1960s. Positive anomalies over China during the period of the 1920s–1940s are noticeable. The temperature increased persistently since the end of the 1960s. The linear trend for the period of 1880–1999 is 0.62°C $(100\,\mathrm{yr})^{-1}$, a little greater than that of the globe 0.60°C $(100\,\mathrm{yr})^{-1}$. 1998 was the warmest year in China since 1880. Studies of the relationship between temperature and precipitation indicated no consistent correlation.

On the basis of multi-taper spectral analysis (Jiang et al., 2001), the statistical analysis of the monthly mean temperature time series in the Northern and Southern hemispheres from 1856 to 1998 showed that the warming trend played a dominant role in mean temperature variability in the Northern and Southern hemispheres during the last 150 years. However, there is significant interdecadal variation with periods of about 40 and 60–70 years, which are superimposed on a linear warming trend for the Northern Hemisphere mean temperature (Fig. 4). This situation leads to the diminishing of the linear warming rate with its significance and stability, as opposed to that in the Southern Hemisphere, especially in summer. Moreover, in comparing surface temperature on

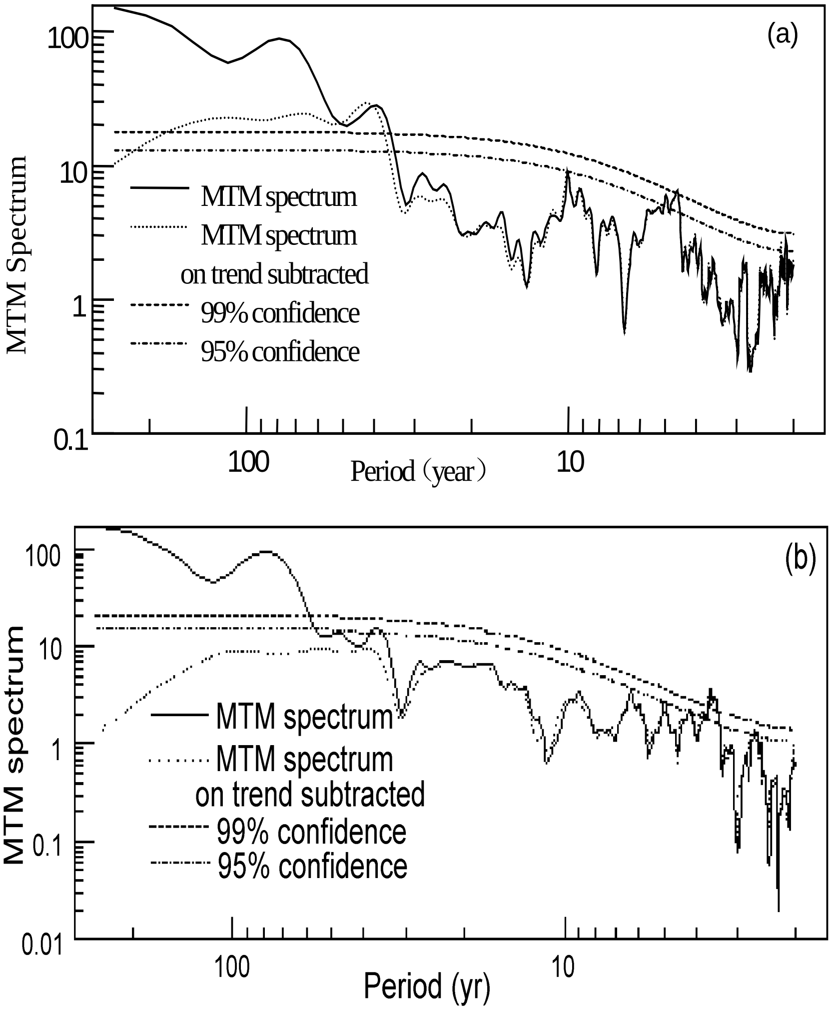

Fig. 4. MTM spectral estimation of the (a) Southern and (b) Northern hemispheres mean surface temperature time series (MTM spectrum based on original series (solid line), MTM spectrum based on time series with trend subtracted off (dotted lines) and the 95% (dot-dashed lines) and 99% (dashed lines) confidence limits based on a robust, red-noise fit to the spectrum). (Jiang et al., 2001).

the land to the sea, interdacadal variations detected in the latter are more remarkable than those in the former, in contrast to the linear warming rate. Furthermore, in terms of the GCM results from the HadCM2 model, a preliminary analysis implied that the interdacadal variation may be the inherent oscillation of the ocean and atmosphere system, but that warming trends are not related to natural variability.

5. NAO/NPO and interdecadal climate variation in China

In recent years, some studies have indicated that the interdecadal variation of the NAO exhibited a rising trend (Hurrell, 1995; Jones et al., 1997). Through data analyses, it is very evident that both the NAO index and NPO index experience variation suddenly in the 1960s, such that their common characteristics were represented by the abnormal rising of the amplitude, where the amplitude after the 1960s was about 2–3 times greater than before the 1960s (Li and Li, 1999a). The wavelet analyses for temporal variations of the NAO and NPO respectively show that interdecadal variations of the NAO and NPO are very clearly represented (figure omitted). First, the amplitudes of the NAO and NPO increased abnormally since the 1960s. Second, it is very evident that the interannual variations with a 3–4-year period were fundamental both the NAO and the NPO before the 1960s, but the decadal variations with an 8–15-year period have been fundamental since the 1960s. Therefore, both the NAO and the NPO experienced anomalous variations, which were not only represented in the amplitude increasing but also in the changing of the period for the dominant mode from 3–4 years to 8–15 years. In other words, the increasing of amplitude since the 1960s is not only represented in the NAO but also in the NPO. Therefore, this kind of interdecadal variation not only exists in the North Atlantic region, but it seems to also occur in other regions.

The climate jump in the China in 1960s was indicated in some studies (Yamamoto et al., 1986; Yan et al., 1990). It still appeared clearly in the summer (June–August) precipitation anomaly (%) in North China, where there were mainly positive precipitation anomalies before 1964 but mainly negative precipitation anomalies from and after 1964, and where the averaged summer precipitation changed suddenly from being above normal to being below normal (Li, 1992). The surface air temperature anomaly in winter (December–February) in Sichuan also changed into a cold period (negative temperature anomalies) since 1962, even though positive anomalies during shorter time periods were in existence (Li and Li, 2000). Obviously, it is very evident that a climate jump occurred in the 1960s and the interdecadal climate variation in China was demarcated in the 1960s. These results can suggest that the interdecadal variations of the NAO and NPO are closely related to the climate jump in the 1960s. Although it is difficult to say that the climate jump in the 1960s (or interdecadal climate variation) in China resulted from atmospheric circulation variation, particularly from the interdecadal variation of the NAO and NPO; but at least, the above analysis results can suggest that the climate jump in the 1960s, or the interdecadal climate variation in China, is closely related to the interdecadal variation of the NAO and the NPO.

The influence of the NAO variation on the East-Asian monsoon and climate was studied preliminarily by Wu and Huang (1999) who indicated that the Siberian cold high would be affected by the NAO variation at first in winter, then the anomalous Siberian cold high could affect the cold waves (winter monsoon) and the climate (including summer rainfall) in East Asia. This occurs because a strong (weak) East-Asian winter monsoon is closely related to a strong (weak) Siberian cold high and a strong (weak) NAO index.

Based on the climate jump in the 1960s and its relationship to the anomalies of the NAO and NPO, it can be suggested that the atmospheric circulation anomaly, which is represented by the NAO and NPO, is also a possible important factor causing interdecadal climate variation in China.

6. Interdecadal mode of SSTA in the North Pacific and its impact

In order to understand the interdecadal variation of the SSTA in the North Pacific Ocean (meaning the Pacific Ocean north of 10°S latitude in this study), the interdecadal mode of the North Pacific SST and its evolution features are investigated further by using the Hadley Center monthly data (1900–1997) but in a different way from EOF analysis (Xian and Li, 2003). The spectrum analyses of the SSTA in the North Pacific showed that two common, main spectrum peaks can be found, one with a period of about 7–10 years and the other with a period of about 25–35 years. The wavelet analysis results of the SSTA in the North Pacific also showed that the 7–10-yr and 25–35-yr periods are two fundamental periods. Therefore, the variations with 7–10-yr and 25–35-yr periods can be regarded as two major interdecadal modes, although there are still other periods.

In order to show the pattern of the two interdecadal modes of the SSTA variation in the North Pacific, band-pass filterings of the SST in the North Pacific with a 7–10-year filter and a 25–35-year filter are respectively performed and the patterns of the two modes are obtained. In Fig. 5, the basic situations of the positive phase and negative phase of the 25–35-yr mode and 7–10-yr mode are shown. For the positive phase, there is positive SSTA in the area of 30°–50°N and west of 140°W; but negative SSTA in the area south of 30°N and along the coast of North America. For the negative phase, there is positive SSTA in the area south of 30°N and along the coast of North America; but negative SSTA in the area of 30°–50°N and west of 140°W. Although the pattern of the 7–10-yr mode is similar to that of the 25–35-yr mode, we do not want to compose them into one. They exist independently in the spectrum analysis results, so it is unsuitable to compose them into one artificially.

The fundamental patterns of the interdecadal mode of the North Pacific SSTA are different from the "ENSO-like mode" although the above modes also showed that the signal is stronger in the mid-latitudes than in the Tropics. The basic character of the ENSO mode should be as follows: positive (negative) SSTA within the limited scope of the equatorial eastern Pacific and maximum SSTA nearby the equator; and a band-type negative (positive) SSTA in a southwest-northeast direction from the equatorial western Pacific to the northeastern Pacific but positive (negative) SSTA in the northwestern Pacific. However, the pattern of the interdecadal mode of the North Pacific

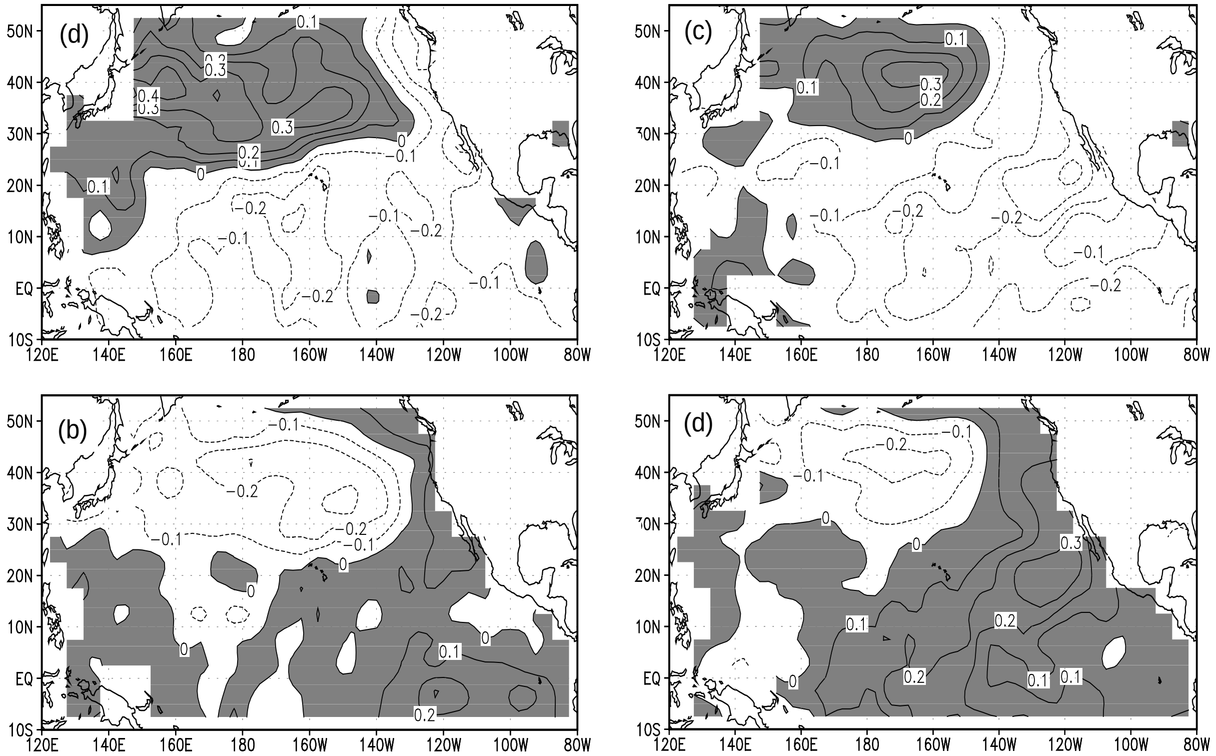

Fig. 5. The patterns of the interdecadal mode of the North Pacific SST in positive phase (a) and negative phase (b) for 25–35-yr mode; in positive (c) and negative (d) phases for 7–10-yr mode. (Xian and Li, 2003)

SSTA has a consistent symbol SSTA in the equatorial Pacific, the western Pacific, and the northeastern Pacific, so the features of the ENSO mode are not clear there.

The impacts of the interdecadal mode of the North Pacific SSTA on the climate were studied by using data analysis (Li and Xian, 2003). The composite analyses of sea level pressure (SLP) corresponding to the 25–35-yr mode of the North Pacific SSTA showed that during winter when the positive phase of the North Pacific SSTA 25–35-yr mode appears, positive SLP anomalies are found north of 30°N in the Pacific region, with a maximum of 4hPa located near the Aleutian Islands, indicating a weak Aleutian low in that period (Fig. 6a). Positive anomalies are also found over Siberia and the North Atlantic Ocean indicating a strengthened Siberian high and a weak Icelandic low; furthermore, negative anomalies with a smaller amplitude appear on the North American continent, suggesting a weak North American high in that period. During winters when the negative phase of the 25–35-yr mode is present, an opposite SLP anomaly pattern over the North Pacific emerges. There are negative anomalies over the North Pacific, centered at the Aleutian Islands with a maximum of 4 hPa, smaller negative anomalies over the North Atlantic, positive anomalies over most parts of the North American continent, and weak positive anomalies over the North Eurasian continent (Fig. 6b). The SLP anomalies over the North Pacific are most directly affected by SSTA. Therefore when SSTA changes its polarity from positive to negative, the sign of the SLP anomalies is also changed correspondingly.

During winter when the positive (negative) phase of the North Pacific SSTA 7–10-yr mode appears, the anomalous patterns of the SLP field are similar to those of 25–35-yr mode positive (negative) phase. This means that corresponding to the positive or negative phase of the 7–10-yr mode or 25–35-yr mode of the North Pacific SSTA, the global sea level pressure field generally has identical responses. In other words, similar anomalous SLP patterns correspond to similar SSTA distributions in the North Pacific, which fully reveals the significant impacts of interdecadal SSTA modes (variations) in the North Pacific on the atmospheric circulation and climate.

The anomalous patterns of the 500-hPa height and 1000-hPa wind field in wintertime corresponding to the positive/negative phases for the 25–35-yr mode and 7–10-yr mode are analyzed. It can be shown that anomalous patterns of the SLP and 500-hPa fields are very similar to each other, and the anomalous wind field is systematically coordinated to the anomalous SLP

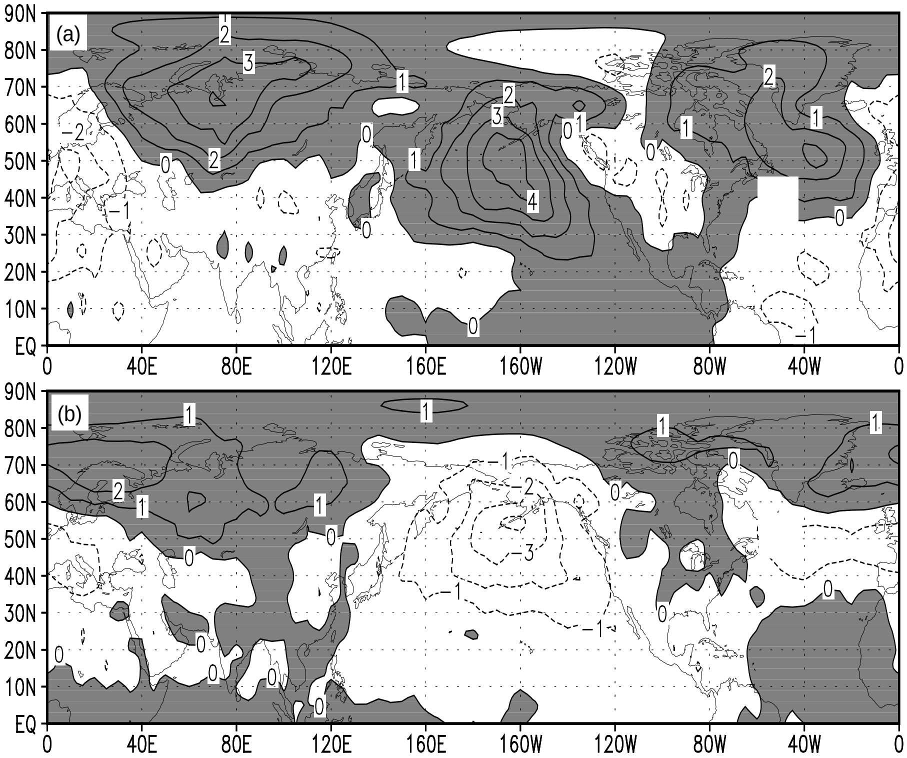

Fig. 6. The SLP anomalies (hPa) in winter corresponding to the (a) positive and (b) negative phases of the SSTA 25–35-yr mode in the North Pacific. (Li and Xian, 2003)

field. Furthermore, comparing the spatial signatures of the response fields of the SLP and 500-hPa height in the extratropical North Pacific and tropical Pacific, we find a positive correlation (response) in the extratropical region and a negative correlation (response) in the tropical region, i.e., a positive (negative) SLP anomaly in the extratropical region results from positive (negative) SSTA, but a negative (positive) SLP anomaly in the tropical region results from positive (negative) SSTA.

The anomalous field of annual global land precipitation is analyzed corresponding to the two phases of each interdecadal mode (Li and Xian, 2003). The results clearly show that the global precipitation pattern is closely related to the interdecadal modes of the North Pacific SSTA. During years when the positive phase of the SSTA 25–35-yr mode in the North Pacific occurs, there is more precipitation in eastern and southeastern Asia, but less precipitation in southern North America. In Australia, there is more precipitation in the east, and less in the west. During years when the negative phase of the SSTA 25–35-yr mode in the North Pacific appears, there is less precipitation in eastern and southeastern Asia, but more precipitation in southern North America. In Australia there is less precipitation in the east, and more in the west (Fig. 7).

A similar precipitation anomalous field is also found corresponding to the North Pacific SSTA 7–10-yr mode. During years when the positive phase is present, there is more precipitation in eastern China; for North America, there is less precipitation in the east and south, and more in the west. There is less precipitation in central and southern South America, and more precipitation in eastern Australia and central Africa (figure omitted). During year when the negative phase appears, there is less precipitation in eastern China, more precipitation in eastern and southern North America, less in northwestern North America, and more in central and southern South America and less in central Africa.

7. Abrupt climate change

The climate variation, particularly the long-term climate variation (change), usually shows an abrupt change feature. Some data analyses have indicated that there are evident climate (temperature and precipitation) abrupt changes in China during the 1920s and during the 1960s (Yan et al., 1990; Yan, 1992; Ye

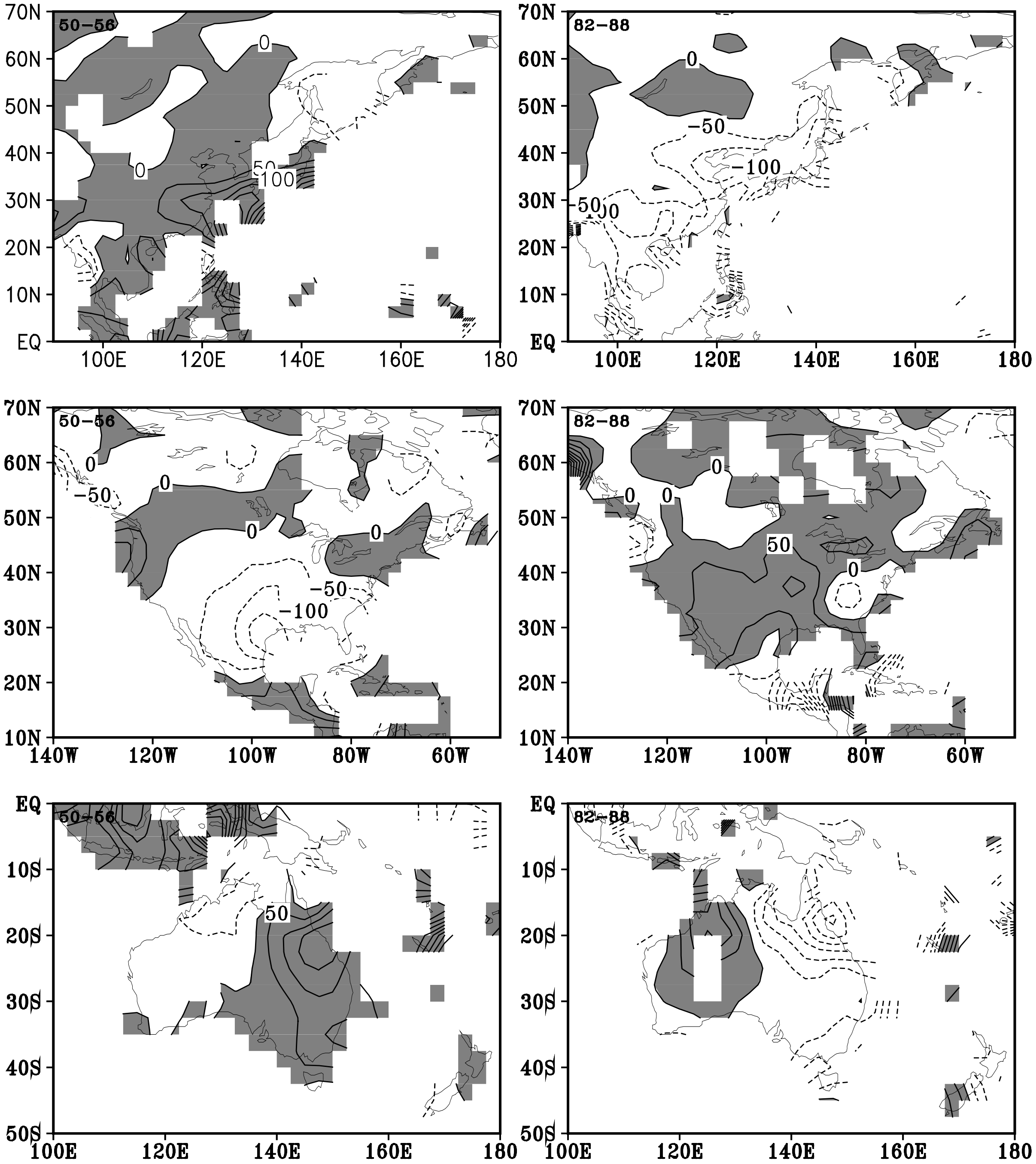

Fig. 7. Annual precipitation anomalies corresponding to the positive (left) and negative (right) phases of the North Pacific SSTA 25–35-yr mode. Top: in East Asia; middle: in North America; bottom: in Australia. (shading represents positive anomaly). (from Li and Xian, 2003)

and Yan, 1993). A statistical test method named the Mann-Kendall Rank examination is available to determine climate abrupt change. As an example, by using the Mann-Kendall test result of the drought index in eastern China during 1887–1986, it is shown that the abrupt changes occurred at 1922 and 1965, which represented a variation from the relatively moist period to the relatively dry period in eastern China (figure omitted).

Some studies have also shown that the jump variations of summer precipitation in eastern China are clear. The data analyses using the recent 50 years of data showed that summer precipitation over the Huabei region displayed two jump variations, in the middle of the 1960s and at the end of the 1970s, respectively (Chen, 1999). Further analysis showed that the jump variation around 1965 was mainly the reduction of precipitation over the Huabei region, and the character of jump variation around 1976 was the increase of precipitation in the Yangtze River basin but continued decrease of precipitation over the Huabei region (Huang et al., 1999).

Using the Mann-Kendall Rank examination, the abrupt change of summer rainfall over North China and the low-mid Yangtze River basin was also found around the mid-1970s (Li and He, 2000). This abrupt change was related with the anomaly of the East Asian summer monsoon (EASM). The stronger EASM lead to more summer rainfall amount in North China, as contrasted to the low-mid Yangtze River basin before 1976. And the opposite situation was observed after 1976. The analysis still showed that the EASM anomaly is closely correlated to SSTA in the North Pacific, which affected the interannual variation of summer rainfall in North China before the mid-1970s. After the mid-1970s, the EASM anomaly was closely related to SSTA in the equatorial eastern-central Pacific instead of the North Pacific SSTA, and the impact of the equatorial eastern-central Pacific SSTA on summer rainfall over the low-mid Yangtze River basin was enhanced. Furthermore, the analyses still showed that the air-sea temperature difference over the North Pacific displayed a significant interdecadal change (Fig. 8). Before the mid-1970s, there was a greater air-sea temperature difference over the North Pacific, which means the SSTA have a stronger impact upon the atmosphere, so that the relation of the North Pacific SSTA with the EASM circulation was enhanced. But after the mid-1970s, the air-sea temperature differences were lower and the effect of SSTA on the atmosphere was insignificant, and there was a weaker relation between the North Pacific SSTA and the ESAM.

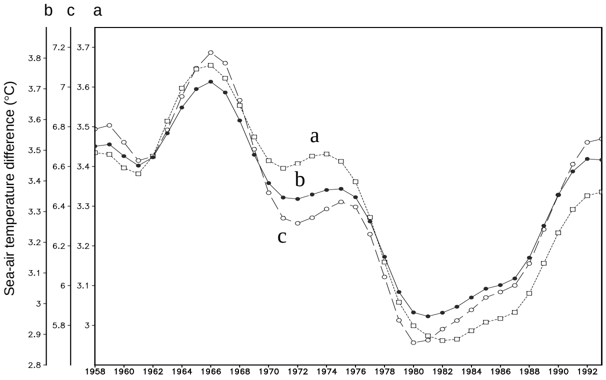

Fig. 8. Time series of a 9-point running mean air-sea temperature difference over the North Pacific: (a) SST-$T_{925\ \mathrm{hPa}}$; (b) SST-$T_{1000\ \mathrm{hPa}-850\ \mathrm{hPa}}$; (c) SST-$T_{850\ \mathrm{hPa}}$. (from Li and He, 2000)

8. Conclusions

(1) The long-term climate (precipitation and temperature) variability in China has multiple timescale features. Except for interannual variation, the decadal/interdecadal variation, the 20–40-yr, around 10-yr and 60–80-yr, are major periods. These decadal/interdecadal climate variations are related to the SSTA in the Pacific.

(2) The East Asian summer monsoon (circulation and precipitation) also has quite evident decadal/interdecadal variation.

(3) The warming trend plays a dominant role in the mean temperature variability in the Northern and Southern hemispheres during the last 150 years. However, the significant interdecadal variation was superimposed on a linear warming trend of mean temperature, particularly, in the Northern Hemisphere.

(4) The temporal variations of the NAO and NPO very clearly show that the amplitudes of these two oscillations increased suddenly in the 1960s and their main period of interannual variations changed from 3–4 years to 8–15 years. These evident variations of the two oscillations in the 1960s represented a fundamental anomaly in the atmospheric circulation in the 1960s. The climate jump that occurred in the 1960s was related to the anomalies of the NAO and NPO, and it can be suggested that the atmospheric circulation anomaly, which is represented by the NAO and NPO, is also a possible important factor causing the interdecadal climate variation in China. The atmospheric circulation anomalies can also be regarded as an important way to understand interdecadal climate variation and the climate jump.

(5) The interdecadal variation of the North Pacific SST has two fundamental modes, the 7–10-year mode and the 25–35-year mode. These two interdecadal modes have similar patterns, particularly their fundamental patterns for positive phase and for negative phase. Whether in the positive phase or negative phase, the pattern of the interdecadal mode is different from the "ENSO-like mode". From the analyses, it can be suggested that the evident oscillation in the northwest-southeast direction and the clockwise rotation along the Pacific Ocean basin are the common evolution features of the interdecadal mode of the North Pacific SST.

(6) Corresponding to the positive and negative phases of the interdecadal mode of the SSTA in the

North Pacific, the anomalous patterns of the atmospheric circulation/climate are very different. This means the impact of the interdecadal mode of the SSTA in the North Pacific on the atmospheric circulation/climate is very clear. The global SLP field has similar responses to the same phases of the 25–35-yr mode and the 7–10-yr mode of SSTA in the North Pacific. The 500-hPa height anomaly patterns are similar to the SLP anomaly patterns, which implies the response of the extratropical atmosphere to the interdecadal modes of SSTA in the North Pacific exhibits a barotropical structure, but the response of the tropical atmosphere shows a baroclinic structure. The global 1000-hPa wind field has an analogous response corresponding to the two interdecadal modes of SSTA in the North Pacific. The anomalous wind field has a systematic structure and is very coherent with the anomalous SLP field.

The impact of the interdecadal mode of SSTA in the North Pacific on regional annual precipitation is not negligible. During years when the positive (negative) phase of the interdecadal modes appears, some regions have less or more precipitation. For example, during the positive (negative) phase period, there is more (less) precipitation over eastern China, less (more) over southern North America, and a band of increased precipitation in eastern (western) Australia.

(7) The climate variation, particularly the long-term (decadal/interdecadal scale) climate variation (change) usually shows an abrupt change feature. The Mann-Kendall Rank analyses showed that in the last century three abrupt changes occurred respectively in 1920–1925, 1960–1965, and the mid-1970s.

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