Interdecadal Variability of Temperature and Precipitation in China since 1880

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ABSTRACT

Reconstruction of a homogeneous temperature and precipitation series for China is crucial for a proper understanding of climate change over China. The annual mean temperature anomaly series of ten regions are found from 1880 to 2002. Positive anomalies over China during the 1920s and 1940s are noticeable. The linear trend for the period of 1880–2002 is 0.58°C $(100a)^{-1}$, which is a little less than the global mean (0.60°C $(100a)^{-1}$). 1998 was the warmest year in China since 1880, which is in agreement with the estimation of the global mean temperature. The mean precipitation on a national scale depends mainly on the precipitation over East China. Variations of precipitation in West China show some characteristics which are independent of those in the east. However, the 1920s was the driest decade not only for the east, but also for eastern West China during the last 120 years. The most severe drought on a national scale occurred in 1928. Severe droughts also occurred in 1920, 1922, 1926, and 1929 in North China. It is noticeable that precipitation over East China was generally above normal in the 1950s and 1990s; severe floods along the Yangtze River in 1954, 1991, and 1998 only occurred in these two wet decades. An increasing trend in precipitation variations is observed during the second half of the 20th century in West China, but a similar trend is not found in East China, where the 20- to 40-year periodicities are predominant in the precipitation variations.

Key words: interdecadal variability, temperature, precipitation, China

1. Introduction

Examination of climate change depends fully on the availability of a homogeneous and consistent dataset. Systematical observations in China on a national scale began at 1951. This dataset consists of monthly mean temperature and monthly total precipitation observations at 160 stations, which nearly cover the whole land areas of the nation except Taiwan. However, observational data is still scarce in some local areas, for example, over the southwest of Tibet.

Analyses of temperature changes since 1951 have indicated that the temperature decreased from the 1950s to the early 1970s, and then increased gradually; the largest warming was found during the later part of the series, especially in winter and in the north part of the country (Hulme et al., 1992, 1994; Ding et al., 1995). The temporal change of annual precipitation differs greatly from that of temperature. Usually, a declining trend has been found from the 1950s to the 1980s in annual total precipitation changes in East China (Li et al., 1990; Wang, 1996). However, interdecadal variability plays a prominent role in this time interval and positive anomalies predominate from the 1950s to the early 1960s, from the early to middle 1970s, and in the 1990s.

The 50-year length of the dataset seems insufficiently long to understand the long-term trend and interdecadal variability of temperature and precipitation. Many efforts have been made to extend the climate series back to the beginning of the 20th century or to the end of the 19th century (Yang, 1956; Yang, 1962; Zhang and Li, 1982; Weather and Climate Institute and Central Meteordogical Observatory, 1984). A graded series of monthly mean temperature and total precipitation since 1910 was constructed by the Weather and Climate Institute of the Chinese Meteorological Administration. Monthly mean temperatures for a calendar month and for each station were grouped into five grades according to observations.

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This method is exactly the same as the one used by Namias (1953) in studying long range forecasts in the U. S. It avoids finding a consistent normal time to calculate the departure from the normal. To grade observations is nearly free of any impact on the series. The grades of missing data are easily to interpolated according to the grades in neighboring stations.

Zhang and Li (1982) firstly indicated, on the basis of temperature grade data, that temperature changes over China were nearly parallel to those over the globe. Wang (1990) constructed an annual mean temperature series for China, which combined station data (1880–1910) and grade data (1911–1988); the latter was transformed into temperature anomalies. Unfortunately, only data from four stations (Harbin, Beijing, Shanghai, and Guangzhou) were applied in Wang (1990), and all of them were located in coastal regions. The inhomogeneity of the series is obvious. Lin and Yu (1990) and Lin et al. (1995) also extended the temperature series of China back to 1873 using observational data. But the number of stations used in their study varied significantly from only 5 at the end of the 19th century to 330 in 1950.

The first series of precipitation over China longer than 50 years was established by Zhang (1993). Chen and Ding (1996) updated the temperature and precipitation grade dataset to 1990 and indicated that precipitation was relatively plentiful in the 1910s, 1930s, and 1950s. The driest decade occurred in the 1920s, but no significant dry decade was found in the second half of the 20th century. These works have improved the understanding of the trend and variability of precipitation in East China.

The reconstruction of a new temperature series over China is described in section two. And the construction of a seasonal precipitation series of East China and the decadal variability of annual precipitation in West China are presented in subsequent sections.

2. Reconstruction of new temperature series over China

Both identical numbers and similar coverage of stations are essential to construct a homogeneous national temperature series. Variance of the national mean temperature depends on the number of stations used in the construction. A great portion of the land area of the country is devoid of meteorological observations during the late 19th and the early 20th centuries. This significantly influences the representativeness of the mean value for the nation.

Therefore, the first step in the construction of a national mean temperature series is to divide the area of the country into ten regions. The key stations for each region are listed in Table 1. The geographical locations of the stations are shown in Fig. 1. The ten regions and their key stations are identified according to the study of Zhang and Li (1982) and an EOF analysis of available observations.

The borders between the regions are found based

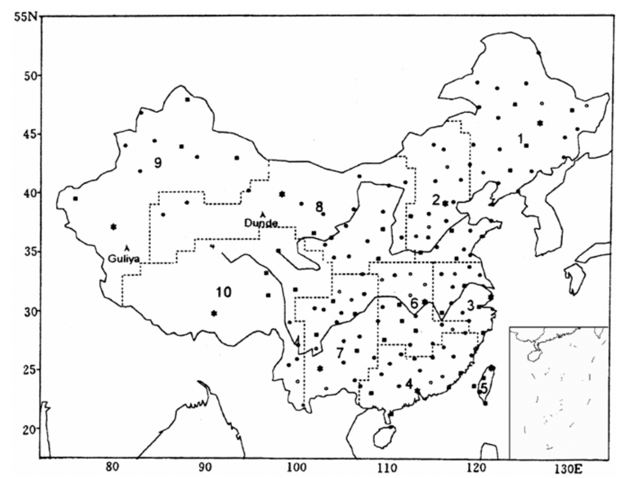

Fig. 1. Ten climatic regions by number, and position of 160 stations over China. The key stations and central stations are marked by dots and stars, respectively.

Table 1. Key stations used in the reconstruction of regional temperature series.

No.	Region	Key stations
1	Northeast	Qiqihar, Jiamusi, Harbin*, Changchun, Shenyang
2	North	Beijing*, Taiyuan, Jinan, Zhengzhou, Xuzhou
3	East	Nanjing, Shanghai*, Hangzhou, Jiujiang, Wenzhou
4	South	Nanning, Guangzhou*, Shantou, Xiamen, Zhanjiang
5	Taiwan	Taipei*, Taichung, Tainan, Penghu, Hengchun
6	Central	Wuhan*, Yichang, Changsha, Changde, Zhijiang
7	Southwest	Chengdu, Chongqing, Xichang, Guiyang, Kunming*
8	Northwest	Yan'an, Xi'an, Lanzhou, Xining, Jiuquan*
9	Xinjiang	Altay, Ürümqi, Hami, Kashi, Hotan*
10	Tibetan Plateau	Lhasa*, Qamdo, Yushu, Madoi, Garẑe

Note: * marks the central station of each region.

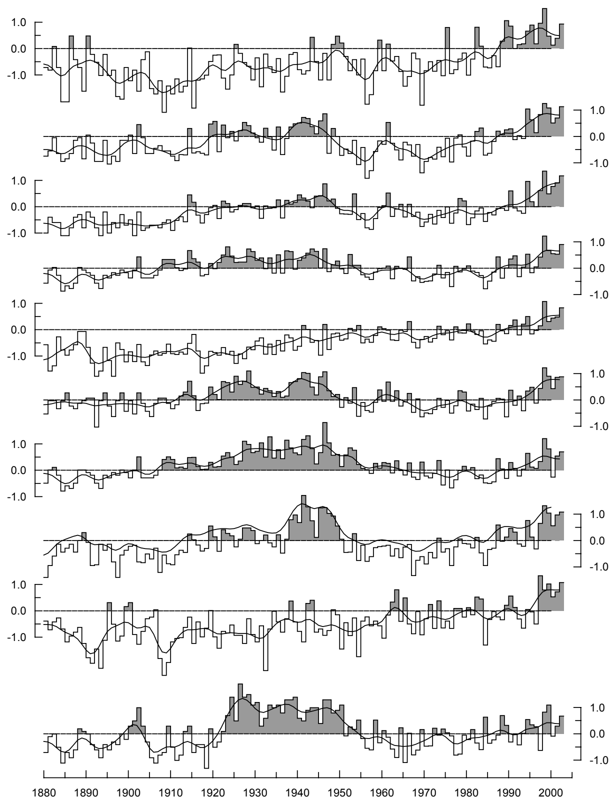

Fig. 2. Variations of annual mean temperature anomalies (°C) in the ten regions from 1880 to 2002. From top to bottom, each panel represents the annual mean temperature anomalies for a climatic region outlined in Table 1. The solid curves show low frequency variations.

on the correlation coefficients (CCs) of temperature between the key stations and 1°×1° grid points over China for the period of 1961–1990. Then, the regional temperature series are constructed by averaging the observational data over the five key stations for each of the ten regions for the period of 1951–2002.

During the period of 1911–1950, temperature grade data are available (Weather and Climate Institute and Central Meteorological Observatory, 1984) for the ten regions except Xinjiang, Tibetan Plateau, and Taiwan. Temperature observations are available in Taiwan for this period. Temperature grades for the remaining seven regions are transformed into temperature anomalies according to the ratio of grade to temperature anomaly, which varies from month to month and from place to place. The grade data are used for this period because the gaps are easily filled in by the grade map. This provides a consistent series of proxy temperature data. Studies have indicated that temperature anomalies in Xinjiang correlate closely to ice core δ^{18}O in Guliya (Wang et al., 1998). CCs vary from 0.25 to 0.35, which reach significance at the 95% confidence level. Therefore, the annual mean anomalies of δ^{18}O in Guliya from 1880 to 1950 are normalized relative to the normal period of 1961–1990. These are then multiplied by the temperature variance of Xinjiang for the period of 1961–1990 to construct the temperature anomaly series representing temperature variations in Xinjiang before 1951. In Tibetan Plateau, few temperature observations are available before 1951. The gaps in the observations are filled in with tree-ring data. It is believed that the latter correlates closely to temperature anomalies in Tibetan Plateau (Lin and Wu, 1977).

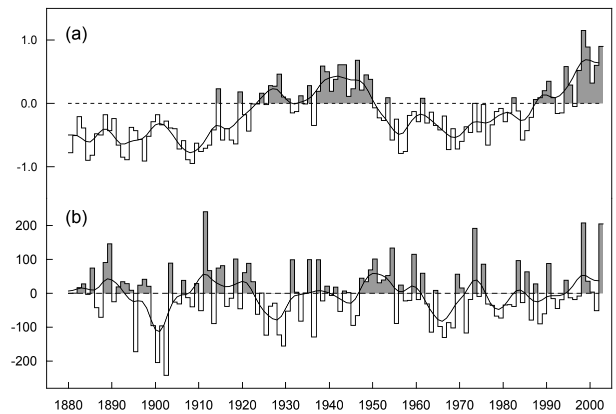

Fig. 3. Temporal variations of (a) annual mean temperature anomalies over China and (b) annual precipitation in East China from 1880 to 2000. Positive anomalies are shaded. The solid curves show low frequency variations.

Since no grade data can be used during the period of 1880–1910, the construction of the temperature series has to rely upon observations from a single station in each of the first five regions, which are shown with stars in Table 1. Even so, only the series of Shanghai and Beijing are complete, whereas the series of Harbin, Guangzhou, and Taipei began sometime later than 1880. Wang (1990) filled the gaps in the series of Harbin and Guangzhou with observational data of Nemuro in Hokkaido, Japan, and of Hong Kong, respectively. A few gaps in Taiwan's series are filled with documentary data. In both the Central and Southwest regions, the annual temperature grade is identified according to documentary data when observation is obscure (Wang et al., 1998). Firstly, the temperature grade is estimated based on historical documents and then transformed into temperature anomalies using the normal distribution of temperatures for the period of 1961–1990. The methodology of the transformation was described in detail by Wang et al. (1998). δ^{18}O anomalies in Dunde were used to reconstruct the temperature in Northwest China, as done for Xinjiang.

Finally, the annual mean temperature anomaly series of the ten regions are completed from 1880 to 2002 (Fig. 2). Temperature anomalies are obtained relative to the normals of 1971–2000. Figure 3a shows the tem-

Table 2. Availability of observational precipitation data.

Station	Beginning	missing data years	
		1880–1899	1900–1950
Harbin	1898	18	8
Changchun	1909	20	13
Shenyang	1906	20	10
Chaoyang	1908	20	26
Hohhot	1920	20	21
Beijing	1840	4	7
Taiyuan	1916	20	29
Jinan	1916	20	16
Zhengzhou	1931	20	41
Xuzhou	1915	20	28
Yantai	1886	16	12
Nanjing	1905	20	6
Shanghai	1873	0	0
Jiujiang	1885	5	12
Wenzhou	1883	4	0
Fuzhou	1880	7	0
Taipei	1897	17	0
Hengchun	1897	17	0
Xinyang	1922	20	41
Yichang	1882	2	12
Wuhan	1880	1	9
Changsha	1909	20	16
Ji'an	1930	20	30
Guilin	1916	20	16
Nanning	1907	20	7
Guangzhou	1908	20	7
Shantou	1880	0	7
Zhanjiang	1951	20	51
Yinchuan	1935	20	47
Lanzhou	1932	20	32
Xi'an	1922	20	25
Chengdu	1906	20	17
Chongqing	1891	11	0
Guiyang	1921	20	0
Kunming	1901	20	7
Total		542	553

perature series of China, which is averaged over the ten regions considering the regional weights, which are proportional to the sizes of regional areas. Positive anomalies over China during the 1920s and 1940s are noticeable. The linear trend for the period of 1880–2002 is 0.58°C $(100a)^{-1}$, which is a little less than the global trend (0.60°C $(100a)^{-1}$). 1998 was the warmest year in China since 1880, which is in agreement with the estimation of the global mean temperature (Wang and Gong, 2000; Wang et al., 2001). The warming trend found on the basis of the new series is much greater than that estimated by using incomplete data (Wang, 1991; Yi and Wang, 1992).

3. Construction of a seasonal precipitation series for East China

It has been demonstrated that the variability of precipitation averaged for China depends mainly on the precipitation over East China (east of 110°E) (Wang et al., 2000). And variations of precipitation in some areas of West China even show a negative correlation to the national mean. Therefore, precipitation variations should be studied separately for the eastern and western parts of China.

There is also another strong reason to examine precipitation variability in the east independently of West China. Proxy data sources of precipitation are quite different in these two parts of the country. Documentary-based precipitation data are plentiful in the east, but are obscure in the west. Fortunately, a great deal of tree-ring data provides important information of precipitation variability in West China.

A total of 35 stations are selected to form a homogeneous series according to the availability and quality of observations (Table 2). Incidentally, all of these 35 stations are located in areas with 0.2 or greater CCs to the national mean precipitation. The availability of precipitation observations is much better than that of temperature. A total of 13 station-based series with complete precipitation observations began at the end of the 19th century, while temperature observations are only available for 4–5 stations. However, there are still 77.4% of the data are missing for the period of 1880–1899, and 31.0% for the period of 1900–1950. These gaps in observations are filled based on documentary data. Reconstruction of drought/flood grade maps for the last 500 years (A. D.1470–1979) have provided valuable information of precipitation variability in East China. These maps refer mainly to summertime. It is easy to transform the grade of drought/flood into the rainfall anomalies in percentage according to the definitions: grade 1–50%, grade 2–25%, grade 3–0%, grade 4– −25%, grade 5– −50%. Usually, several items of records are used to estimate the precipitation grade in one season at a station, where station-based observations are not available. Gaps in precipitation series in spring, autumn, and winter are filled also by using documentary data as in summer (Wang et al., 2000).

Observational data only are applied in the period of 1951–2002. Figure 4 gives the seasonal precipitation series averaged for 35 stations during the period of 1880–2002. Figure 3b shows the annual precipitation variations. A decreasing trend in precipitation variations is found based on the observations since 1951.

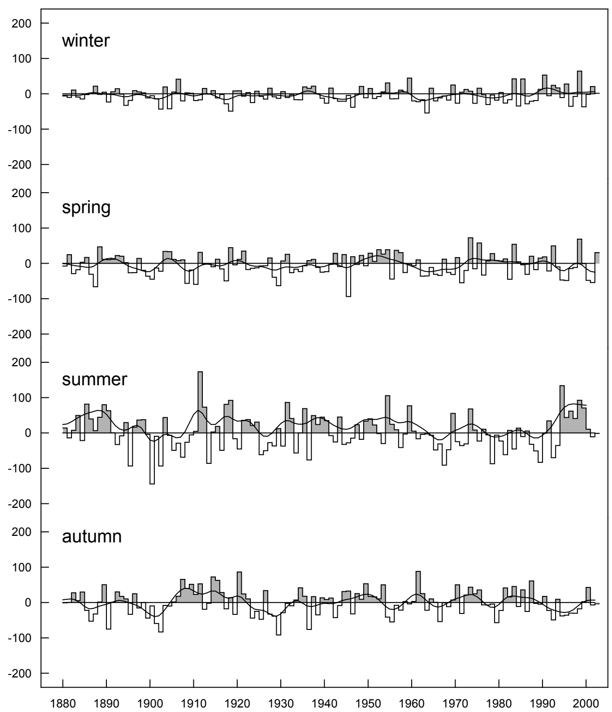

Fig. 4. Seasonal precipitation anomalies averaged for 35 stations during the period of 1880–2002 (mm), positive anomalies are shaded. The solid curve shows low frequency variations.

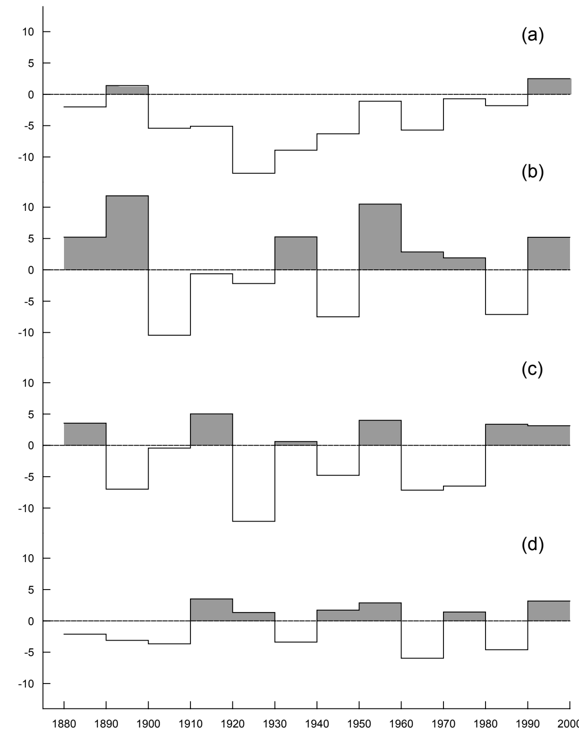

Fig. 5. Decadal mean precipitation anomalies in percentage relative to the period of the 1970s–1990s. (a) West China; (b) North China; (c) Yangtze River; (d) South China.

However, it seems to end in the 1980s. A weak increasing trend is observed in the 1990s. On the other hand, no linear trend occurs during the first period from 1880 to 1950. A 20–40-year periodicity is predominant for the whole series. A power spectrum analysis (no shown here) shows a significant peak around 30 years, and a weaker peak near 3 years.

4. Decadal variability of annual precipitation in West China

In most of the areas of West China, documentary data are scarce and the construction of the precipitation series in the early period mainly relies upon tree-ring data (Li et al., 1977). The climate characteristics there belong to the arid or semi-arid type and annual precipitation is usually less than 200 or 400 mm except in the southeast of the Tibetan Plateau and in the far west of Xinjiang. The changes in tree-ring width in West China reflect the precipitation variations to a great extent. Many papers have contributed to reconstructing the local precipitation series in West China. Therefore, 17 regional series of annual precipitation, which were reconstructed by proxy data, are synthesized to form a composite series for West China. The data sources are outlined in Table 3, with details referred to Wang et al. (2002).

However, for the reconstructed decadal mean precipitation anomalies in percentage, the low frequency variability of precipitation shows greater reliability than the high frequency part. For example, the width of tree rings in each year usually depends not only on the climatic conditions in that year, but also on those in the preceding year or even in the year before the preceding year. CCs between decadal mean widths and precipitation show a higher confidence level than the yearly data consequently, so only variations of decadal mean precipitation for West China are examined.

It should be noted that it is very difficult to estimate the absolute amount of precipitation, for all of the tree-ring data were taken on the border of the forest where usually no precipitation observations occurred. In general, the CCs between width and precipitation vary from 0.4 to 0.5, so the part of the precipitation variance interpreted by the width only varies from 15% to 25%. Therefore, tree-ring data are normalized relative to the normal period of 1961–1990, then multiplied by the variance of annual precipitation of a nearby station. This procedure avoids to some ex-

Table 3. Original series used in reconstruction of decadal mean anomalies of annual precipitation in West China.

No.	Region	Geographical location	Data source	Timing	Original authors
1	Altay	48.0°N, 88.0°E	Tree-ring	1728–1979	Li, 1989
2	North Xinjiang	46.0°N, 87.0°E	Tree-ring	1462–1987	Yuan and Han, 1991
3	Ili	43.5°N, 82.5°E	Tree-ring	1682–1985	Yuan et al., 2000
4	East Xinjiang	43.5°N, 95.0°E	Tree-ring	1685–1979	Yang et al., 1989
5	West Xinjiang	43.0°N, 81.0°E	Tree-ring	1733–1982	Wang, 1997
6	West of Yellow River	40.0°N, 98.5°E	Documentary	1700–1990	Xu et al., 1997
7	Yulin	39.5°N, 110.5°E	Tree-ring	1515–1987	Li, 1997
8	Bend of Yellow River	38.5°N, 106.5°E	Documentary	1470–1990	Xu et al., 1997
9	Dunde	38.0°N, 96.5°E	Icecore	1610–1980	Yao et al., 1992
10	Qinghai	37.0°N, 98.5°E	Tree-ring	1165–1981	Wang and Zhou, 2000
11	Gansu	36.0°N, 104.0°E	Documentary	1470–1994	Wang et al., 1997
12	Tangnag	35.5°N, 100.0°E	Documentary	1736–1998	Feng and Ke, 2000
13	Huangling	35.5°N, 109.5°E	Tree-ring	1647–1973	Li et al., 1997
14	Guliya	35.0°N, 82.0°E	Icecore	1570–1990	Yao et al., 1995
15	Huashan Mountain	34.5°N, 110.0°E	Tree-ring	1500–1992	Shao and Wu, 1996
16	Tibet	29.5°N, 91.5°E	Tree-ring	1727–1973	Wu and Lin, 1978
17	Hengduan Mountains	28.0°N, 98.0°E	Tree-ring	1600–1981	Wu et al., 1988

tent the reduction of the variance of the reconstructed series. Most of the series of proxy data ended in the 1980s. They were then updated with observational data. Figure 5a gives the mean precipitation anomalies from the 1880s to the 1990s relative to the normals (1970s–1990s). It shows tremendous drought in the 1920s–1930s and an increasing trend from the 1930s to the end of the 20th century. Decadal mean precipitation anomalies for North China, the Yangtze River valley, and South China are also shown in Figs. 5b–5d for comparison. Decadal variablities of precipitation over the eastern part of China are obvious, and they differ to a great extent from those in West China.

5. Conclusion

The new temperature series for ten climatic regions and for the whole of China are reconstructed. The homogeneity and coverage of these series are considerably improved compared to the early work of Wang (1990). According to this new series, the linear trend of surface air temperature over China for 1880–2002 is 0.58^oC $(100a)^{-1}$, a little less than that of the global mean. Both the seasonal precipitation series over East China and decadal variations of annual precipitation in West China are reconstructed. There is nearly no linear trend during 1880–2002, and a 20–40-year oscillation is predominant in East China. In contrast, the increasing trend of precipitation in West China is very noticeable in the second half of the 20th century.

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REFERENCES

Chen Yuqiong, and Ding Mei, 1996: Variations of seasonal and annual mean climate in China during the last one hundred years. *Proceedings of Climate Change and Numerical Modeling*, Chen Longxun et al., Eds, China Meteorological Press, Beijing, 178–185. (in Chinese)

Ding Yuguo, Tu Qipu, and Wen Ming, 1995: A statistical model for investigating climatic trend turning points. *Adv. Atmos. Sci.*, **12**, 47–56.

Feng Jianying, and Ke Xiaoxin, 2000: *The Variation Features of the Runoff in the Upper Reaches of the Yellow River for 260 Years.* Vol. 2, *The Research on Change and Prediction of Drought Climate in Northwest China,* Xie Jinnan, Ed., 166–170. (in Chinese)

Hulme, M., T. Wigley, Zhao Zongci, Wang Futang, and Ding Yihui, 1992: Greenhouse Effect Induced Climate Change and the Impact on China. CRU/WWF/SMA, Switzerland, 56pp.

Hulme, M., Zhao Zongci, and Tao Jie, 1994: Recent and future climate change in East China. *International J. Climatology*, **14**, 637–658.

Li Kerang, Lin Xuechun, and Wang W-C, 1990: The long-range variational trend of temperature in China from 1951 to 1988. *Geographical Research*, **19**, 26–37. (in Chinese)

Li Jiangfeng, Zhang Zhijia, Yuan Yijiang, and Wu Jinong, 1989: Reconstruction of precipitation in Altay region. *Research on Dendrochronological Climate and Hydrology in Xinjiang*, China Meteorological Press, Beijing, 66–73. (in Chinese)

Li Zhaoyuan, Yang Wenfeng, and Wu Suliang, 1997: Using tree-ring data ancient pines to recover climate in Yulin of Shaanxi Province. *The Research of Drought*

Climate in Northwest China, Sun Guowu, Ed., China Meteorological Press, Beijing, 48–51. (in Chinese)

Li Zhaoyuan, and Coauthors, 1977: The tree-ring and climate change in Shaanxi. *Proceedings of Climate Change and Long-term Prediction*, Science Press, Beijing, 72–76. (in Chinese)

Lin Xuechun, and Yu Suqiu, 1990: Climatic trend in China for the last 40 years. *Meteor. Monthly*, **10**, 16–21. (in Chinese)

Lin Xuechun, Yu Suqiu, and Tang Guoli, 1995: Series of average air temperature over China for the last 100-year period. *Chinese J. Atmos. Sci.*, **19**, 525–534. (in Chinese)

Lin Zhenyao, and Wu Xiangding, 1977: Investigation of climate change over Tibetan Plateau in historical time. *Proceedings of Climate Change and Ultra-Long Range Forecasting*, Institute of Chinese Central Meteorological Administration, Science Press, Beijing, 23–28. (in Chinese)

Namias, J., 1953: *Thirty-Day Forecasting: A Review of a Ten-Year Experiment. Meteor. Monogr.*, No. 6, Amer. Meteor. Soc., 83pp.

Shao Xuemei, and Wu Xiangding, 1996: Reconstruction of April to June precipitation in Huashan area using tree rings, 1500–1992. *Global Change and Future Environment in China*, Fu Congbin and Yan Zhongwei, Eds., China Meteorological Press, Beijing, 17–27. (in Chinese)

Wang Baoming, 1996: Analysis of trend in a standard precipitation time series of China. *Proceedings of Climate Change and Numerical Modeling*, Chen Longxun et al., Eds., Beijing, 200–206. (in Chinese)

Wang Baoling, Sun Guowu, Li Ying, and Lu Juxiang, 1997: An analysis of drought/flood jumps during the recent 525 years in Gansu Province. *The Research of Drought Climate in Northwest China*, Sun Guowu, Ed., China Meteorological Press, Beijing, 42–47. (in Chinese)

Wang Chengyi, 1997: The feature of changes in dry-wet for nearly 250 years in the west of Xinjiang. *The Research of Drought Climate in Northwest China*, Sun Guowu, Ed., China Meteorological Press, Beijing, 27–30. (in Chinese)

Wang Shaowu, 1990: Trend in temperature variations in China and around the world for the last one hundred years. *Meteor. Monthly*, **16**, 11–15. (in Chinese)

Wang Shaowu, 1991: Global climate warming and its trend in the future. *Chinese Quaternary Sciences*, **3**, 269–276. (in Chinese)

Wang Shaowu, and Gong Daoyi, 2000: Enhancement of the warming trend in China. *Geophys. Res. Lett.*, **27**(16), 2581–2584.

Wang Shaowu, Gong Daoyi, and Zhu Jingong, 2001: Twentieth-century climatic warming in China in the context of the Holocene. *The Holocene*, **11**(3), 313–321.

Wang Shaowu, Gong Daoyi, Ye Jinlin, and Chen Zhenhua, 2000: Seasonal precipitation series over China since 1880. *Acta Geographica Sinica*, **55**, 281–293. (in Chinese)

Wang Shaowu, Ye Jinlin, Gong Daoyi, Zhu Jinhong, and Yao Tandong, 1998: Construction of mean annual temperature series for the last hundred years in China. *Quart. J. Appl. Meteor.*, **9**, 392–401. (in Chinese)

Wang Shaowu, Cai Jinning, Mu Qiazhen, Xie Zhihui, and Dong Wenjie, 2002: Climate change of annual precipitations in western China. *J. Natural Resources*, **17**(4), 415–422. (in Chinese)

Wang Zhenyu, and Zhou Lusheng, 2000: *The Evolution Characters of Summer Precipitation from 1165 to 1981 in North of Qinghai Province.* Vol. 3, *The Research On Change and Prediction of Drought Climate in Northwest China*, Xie Jinnan, Ed., 79–84. (in Chinese)

Weather and Climate Research Institute and Central Meteorological Observatory, 1984: *Temperature Grade Map, 1911–1980.* China Meteorological Press, Beijing, 443pp. (in Chinese)

Wu Xiangding, and Lin Zhenyao, 1978: The modern climate change in Xizang and its trend. *Chinese Science Bullein*, **23**(2), 746–750. (in Chinese)

Wu Xiangding, Lin Zhenyao, and Sun Li, 1988: A preliminary study on the climatic change of the Hengduan Mountains area since 1600 AD. *Adv. Atmos. Sci.*, **5**(4), 437–443.

Xu Guochang, and Coauthors, 1997: *The Climate Change in Arid and Semi-arid Region in China*. China Meteorological Press, Beijing, 101pp. (in Chinese)

Yang Guangxun, Zheng Xiaoyan, Niu Guozhi, Li Jiangfeng, Xu Ruizhen, and Liu Chuanzhi, 1989: Establishment of tree-ring chronologies in Eastern Xinjiang and study of climatic variation trend. *Research on Dendrochronological Climate and Hydrology in Xinjiang*, China Meteorological Press, Beijing, 37–47. (in Chinese)

Yang Jianchu, 1956: On the occurrence of large scale mean monthly temperature departure in China. *Acta Meteor. Sinica*, **27**, 135–152. (in Chinese)

Yang Jianchu, 1962: The characteristics of temperature variation during recent 50 years in China. *Acta Meteor. Sinica*, **31**, 360–370. (in Chinese)

Yao Tandong, and Coauthors, 1995: The climate change of Guliya icecore since Little Ice Age. *Science in China* (*B*), **25**(10), 1108–1114. (in Chinese)

Yao Tandong, and Coauthors, 1992: The Holocene climate change in Qilianshan mountain using Dunde icecore. *The Holocene Climate and Environment in China*, Shi Yafeng, Ed., Ocean Press, Beijing, 206–211. (in Chinese)

Yi Yuhong, and Wang Shaowu, 1992: Abrupt warming of global climate in 1980s. *Chinese Science Bulletin*, **37**, 528–531.

Yuan Yujiang, and Han Shuti, 1991: Features of dry and wet changes for 500 years in the northern Xinjiang. *Journal of Glaciology and Geocryology*, **13**(4), 315–322. (in Chinese)

Yuan Yujiang, Ye Wei, and Dong Guangrong, 2000: *Reconstruction and Analysis of 314-year Precipitation in Yili Region in the West of Tianshan.* Vol. 3, *The Research on Change and Prediction of Drought Climate in Northwest China*, Xie Jinnan, Ed., China Meteorological Press, Beijing, 261–269. (in Chinese)

Zhang Xiangong, and Li Xiaoquan, 1982: Some characteristics of temperature variation in China in the present century. *Acta Meteor. Sinica*, **40**, 198–208. (in Chinese)

Zhang Mingli, 1993: Variation of mean annual precipitation in Eastern China during recent hundred years. *Chinese J. Atmos. Sci.*, **17**, 451–461. (in Chinese)