Climate in China during the four special periods in Holocene*

WANG Shaowu (王绍武) and GONG Daoyi (龚道溢)

(Department of Geophysics, Peking University, Beijing 100871, China)

Received July 12, 1999; revised September 27, 1999

Abstract Characteristics of temperature over China during the four special periods in the Holocene, i.e. the Megathermal, the Medieval Warm Period, the Little Ice Age and the Modern Warm Period, are analyzed. The Megathermal period was 8.5—3.0 kaBP, the maximum temperature appeared at about 5.5—6.0 ka and 7.0 kaBP, while the temperatures were about 2℃ above the average of the latest one hundred years. During the Medieval Warm Period, from the late 9th century to the 13th century, the temperatures were warmer over eastern China. Some maximum temperatures were close to the mean value in 1880s—1970s. However, the climate in the 12th century was cold. Over the west part of China, temperatures did not show the same features as that over the east except the moderate warmth appeared during the second half of the 9th century. There were five cold spells in China during the last millennium; in the early 12th, 14th and 16th centuries, the late of 15th century, the 17th and 19th centuries. In these cold periods, the last three spells can be considered as the Little Ice Age of China, the minimum of temperature anomaly was below −1.0℃ and −0.5℃ for the 10 years' and 30—50 years' mean respectively. The 20th century was the warmest in the last 12 centuries, and was 0.5℃ warmer than the last 1200 year's mean. During the last one hundred years, the warmest period appeared in 1920s—1940s, but the highest annual temperature occurred in 1998 in which the temperature anomaly was +1.38℃ with respect to the mean temperaure of 1961s—1990s.

Keywords: **Holocene, China, climatic change.**

Recently, great attention has been paid to the climatic changes in China. Large amounts of proxy evidence have been used in studying the climate of the four special periods, i.e. the Megathermal, the Medieval Warm Period, the Little Ice Age and the Modern Warm Period, more and more details have been unraveled. It is of great help to understand the climatic variation in China during the Holocene.

The purpose of this study is to collect and analyze the proxy evidence for summarizing the characteristics of climate of China in the last 10 ka.

1 Megathermal

The Megathermal is usually used to describe the warm periods of interglacial phase. It seems that this terminology may be more reasonable than the Hypsithermal and Climatic Optimum, because the Megathermal might include some cool spells[1].

Due to the lack of documentary evidence in this period, only two pieces of archaeological evi-

* Project supported by "National Key Developing Programme for Basic Sciences" (G1998040900 Part 1) and the National Natural Science Foundation of China (Grant No. 49635190).

dence were shown to support the warm climate in the early times in the pioneer work of "Preliminary study on the climatic change in China during the last five thousand years" by Zhu Kezhen(1973)[2]. Since then, much archaeological evidence has been found, for example, the fossils of many tropical animals such as elephants and rhinoceros found over the middle and low valley of the Yellow River[3,4]. It is clear that there was a warmer period during the Holocene. Shi et al. indicated that the Megathermal covered the period of 8.5—3.0 kaBP in China[1,4].

However, there are some problems with the archaeological evidence. First, the dating was not accurate enough. Second, although there were fossils of tropical animals in northern China, it was difficult to estimate the temperature directly. Third, the fossils offered no help for building a continuous time series. Then, the best proxy for the climate of Holocene may be the pollen. The number of published papers about the pollen analysis had been more than 200 even eight years ago. Shi et al. discussed carefully the climate of China in Holocene mainly according to the pollen data[1,4], and finished the map of vegetation distribution in the Megathermal (7.2—6.0 KaBP) using the pollen data from more than 70 sites. The difference between the maps of the Megathermal and of modern time was checked, then the difference in temperature was estimated. Zhang et al. also calculated the seasonal and annual temperature of the middle Holocene using the pollen data of 49 sites[3].

To get better representative, we chose ten pollen time series for the ten climatological regions over China[5], then the area weighted time series are obtained. For the low resolution in time scale, only four samples are used in every one thousand years, i.e. in the order of 10.0, 9.75, 9.50, 9.25 kaBP, etc., so there are 40 time points from 10 to 0.25 kaBP in total, the anomaly of modern time is 0. The following important common practices should be noticed. (i) The high frequency components from the pollen series have already been filtered out, and thus it can represent the multi-year average of the temperature. (ii) The reference period was varied for different authors, here we try to reduce all the anomalies to that of the last one hundred years. (iii) Different converting functions were used by various authors, we made no change in this paper. The original data of ten regions are shown in table 1. The original converted temperature data were obtained for regions 1, 2, 3, 4 and 7. The temperature series for the other five regions are calculated using the original pollen data. However, as demonstrated in fig.1, the time series constructed by the original temperature data of the five

Table 1 The Megathermal in China

Region	Site	Latitude/°N	Longitude/°E	Time/kaBP	Warmer than now/℃	References
1 East. North	Gushantun	42	126	8.3—4.0	1.7—2.6	[1] 33—39
2 North	East. Hebei	40	118	8.0—4.0	3.0—4.0	[1] 1—18
3 East	Jianhu Lake	34	120	8.5—3.7	1.7	[1] 80—93
4 South	Pear Riv. Delta	23	114	9.0—3.0	1.0	[1] 121
5 Taiwan	Riyuetan Lake	24	121	8.5—3.0	2.0—3.0	[1] 91
6 Central	Dongting Lake	29	113	7.5—4.0	3.0—3.5	[1] 120
7 Sou. East	Guizhou	28	109	7.8—2.7	1.6—3.0	[1] 123
8 Nor. West	Qinghai Lake	37	100	8.0—3.5	3.0	[1] 48—65
9 Xinjiang	Aibi Lake	45	83	8.5—4.0	1.0—3.0	[1] 168—174
10 Tibet	Bangong Lake	34	80	8.3—4.0	3.0—4.0	[1] 197—205

regions do not show much difference from that by all ten regions. Thus, the time series shown in fig. 1 depict the most important temperature features of China during the last 10 ka. Fig. 1 indicates that the Megathermal in China covers 8.5—3.0 kaBP if using the criteria of warm-than-now, and in the maxima (5.5—6.0 and 7.0 KaBP) the annual mean temperature over whole China is +2.0℃ higher than that of the present time.

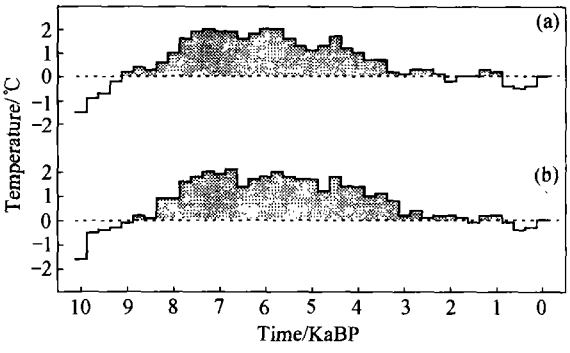

Fig. 1. Temperature of China in Holocene for ten regions mean (a) and five regions mean(b).

2 Medieval Warm Period

It has been suggested that the Medieval Warm Period was around 900—1300A.D. Zhu indicated that the Sui and Tang Dynasies (589—907 A.D.) experienced a climate of warmth[2]. But the temperature decreased during the 11th century, and had a climate of coldness in the 12th century. Around the 13th century the temperature increased a little but then lowered in the 14th century. Then there might be no warm climate during the 10th—13th century, i.e. there was no Medieval Warm Period in China. However, Man[4] has shown a lot of evidence supporting the existence of warmer climate during the 10th—13th century over China. During that period, the northern boundary for planting some crops, such as wheat, rice, sugarcane, tea tree, citrus, ramie, was 1° north to today's. According to Gong et al.[6], the annual average temperature difference between latitudes is about 0.5℃ per one degree of latitude in eastern China. Man[4] indicated that the season came 3—4 days earlier than that of the present in Hangzhou, it was nearly equal to the change for 1° latitude to the north too. Zhang[7] also found that the northern boundary for planting citrus and ramie was more north to today's in the 13th century. Wang[8] constructed the temperature time series of winter and summer of the eastern China back to 800 A.D. However, due to the lack of data in the early time, the time resolution of the series was only 100 years.

Here we collect more historical documentary evidence, as shown in table 2. The time resolution is increased to 50 years. The 10-year-mean annual temperature series since 1400 A.D. are used to construct the converting function between the 50-year-mean coldness index and the temperature anomalies[1]. Thus, the temperatures over eastern China for 800—849, 850—899, 900—949A.D., ···, are computed (fig.2(a)). Recently, Wang et al.[13] have reconstructed the temperatures over the western China for the last millennium. Fig.2(b) shows the 50-year-mean temperature anomalies (with respect to 1880—1970 A.D.) of the average of the three western regions, which are the northern West, Xingjiang and Tibet. In the northern West and Xinjiang, the $\delta^{18}O$ data are used[14,15]; in Tibet the tree ring data are used[16]. Fig.2(c) is the mean of the western and eastern China. Some features are evident as demonstrated by fig.2. (i) The climate over China in the Medieval Warm Period was as warm as that in the 20th century, but there was significant difference between western and

1) Wang Shaowu, Gong Daoyi, Zhu Jinhong, The climate of Medieval Warm Period in China, 1999, unpublished.

eastern China. (ii) In eastern China, there were two warm spells appearing in the late 9th to the late 11th century, and the 13th century. (iii) There was no warm climate over western China during the 10th—13th century. (iv) The coldness occurring in the 12th century was more significant in western China than in eastern China.

Table 2 Sources of the documentary evidences (800—1399 A.D.)

No.	Year(AD)	Dynasty	Proofs	Number	References
1	800—1399	Tang ~ Ming	cold winter	42	[8] 17—18
			warm winter	40	[8] 17—18
			cold summer	34	[8] 18—19
			warm summer	36	[8] 18—19
2	800—941	Mid. Tang ~ Wudai	cold events	12	[4] 292
	960—1100	Northern Song	temp. anomalies	15	[4] 297
	1288—1340	Yuan	heavy snow	13	[4] 299
	962—1228	Song	cold & warm events	67	[4] 439
3	962—1127	Northern Song	cold events	19	[9] 146
	1018—1371	Song ~ Ming	severe cold events	7	[9] 120
	821—1399	Tang ~ Ming	cold winter	36	[9] 156—157
4	627—904	Tang	freeze	33	[10] 73—74
	814—947	Southern Tang, Northern Qi	freeze, hot summer	5	[10] 78
	821—903	Tang	sea ice	2	[10] 92
	962—1237	Song	freeze	36	[10] 172—173
	988—1113	Liao	freeze	7	[10] 175—176
	1197—1232	Jin	freeze	10	[10] 177
	1284—1368	Yuan	freeze	30	[10] 182—183
5	628—902	Tang	frost, snow	10	[11] 26
	647—904	Tang	severe cold events	17	[11] 26
	821—903	Tang	sea ice	3	[11] 26
6	928—1113	Liao	freeze	15	[12] 48—49

3 Little Ice Age

The period of 1550—1850 A. D. was widely known as the Little Ice Age[17]. Zhu[2] indicated that there were three cold episodes for the Little Ice Age in China, during 1470—1520 A. D., 1620—1720 A. D. and 1840—1890 A.D.. The results were supported by some other evidence. Zhu also inferred the degree of the coldness according to the phenology records. Major evidence was extracted from the Diary of Yuan Xiaoxiu (1608—1617 A.D.) and Travel to the North (1653—1655 A.D.). The blooming dates of peach, apricot, clove and some other vegetation showed that the seasons in northern China might be one to two weeks later than the present. The thawing date of the canal in Beijing was twelve days later than that in nowadays. So, Zhu concluded that the winter temperature during the middle 17th century was 2℃ lower than that in nowadays. Gong et al.[6] indicated that the

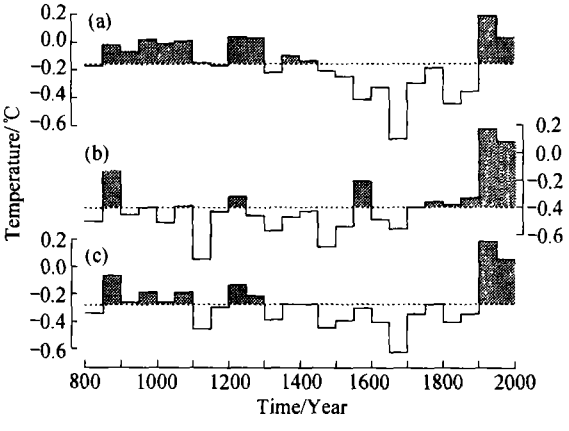

Fig. 2. Temperature of China since 800 A.D. (a) Eastern China; (b) western China; (c) whole China. The mean values of the whole series are shown as the dotted lines.

season in eastern China would be four days later than that in the place of one degree south, and the annual mean temperature and winter temperature would be 0.5℃ and 0.9℃ lower respectively. Therefore, the deduction of Zhu is credible, and an inference can be drawn that the annual temperature during the Little Ice Age was 1℃ lower than that of the present days.

Using plenty of historical documentary evidence, Wang[18] has established the seasonal temperature series of northern China back to 1380 A.D. The temperature anomalies usually obeyed the normal distribution law. There is a certain probability for certain anomaly, and the probability can be calculated in terms of the standard deviation. For example, assuming the standard deviation of the temperature series is 1℃ (close to the observed standard deviation of winter temperature in Beijing), the probability for the anomaly below −0.1℃ is 15.9%, and the probability for that below −2.0℃ is 2.3%. If the climate becomes colder, the whole distribution will shift to the cold side. When the mean temperature drops by 1.0℃, the probability for the anomaly below −2.0℃ is no longer 2.3% but increases to 15.9%. Thus, the climatic change can be estimated by the probability of cold events. This method is fruitful for reconstructing the climate of Little Ice Age as there are plentiful cold events recorded in the historical documents. Fig.3 shows the ten-year-mean temperature series of northern and eastern China. According to these series, the three cold spells are recognized and shown as I, II, and III in table 3.

Table 3 Three cold spells in the Little Ice Age and their temperature anomalies (with respect to the mean of 1880s—1970s, in ℃)

Time	Cold spells						
	I_1	I_2	II_1	II_2	III_1	III_2	Warm period
	1450s—1470s	1490s—1510s	1560s—1600s	1620s—1690s	1790s—1810s	1830s—1890s	1920s—1940s
Northern China	−0.29	−0.06	−0.47	−0.63	−0.45	−0.32	0.49
Eastern China	−0.31	−0.61	−0.47	−0.57	−0.41	−0.58	0.43
Whole China				−0.47	−0.40	−0.30	0.43

Figure 3 also gives the area weighted mean temperature of the ten climatological regions since the 17th century[10], however, because of the lack of data, the temperatures of whole China during the 3 spells of I_1, I_2, and II_1 are uncertain. The temperature anomalies of the whole China during the 3 spells of II_2, III_1, and III_2 are listed in the last row of table 3. It can be briefly concluded that the temperature of Little Ice Age is 0.5℃ lower than the mean of the last one hundred years.

Returning to fig. 2, it is clear that there were five cold periods in China during the last one thousand years: the early 12th and 14th centuries, the late 15th century, the 17th and 19th centuries. Among these cold periods, the last three periods can be considered as the three cold spells of the Little Ice Age.

4 Modern Warm Period

Although the 20th century is just a short period in the Holocene, the related study is very helpful for understanding the modern climate and predicting the climate in the future. Climate research relies greatly on the records from the instruments at near surface weather stations. Unfortunately, the modern large networks of weather observing stations are operated only since 1951 in China. During the

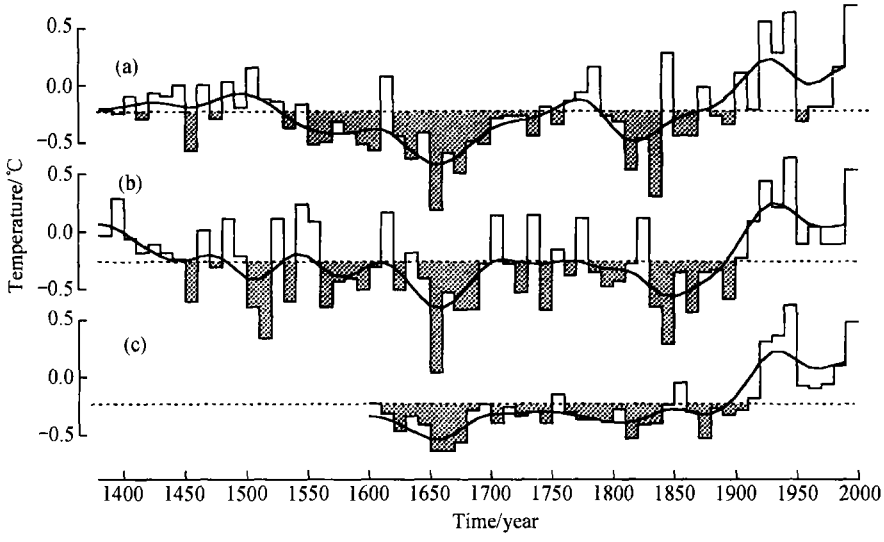

Fig. 3. Temperatures in China since 1380s. (a) Northern China; (b) eastern China; (c) whole China.

past decades some attempts have been made to estimate the annual mean temperature of China back to the late 19th century[19—21]. However, there are some causes that may make temperature series inhomogeneous. Although several long-term stations located in eastern China near the coast were established during the late 19th and early 20th centuries, large gaps in the observed temperature coverage still exist. Especially, the data availability over the western continent of China is very poor. Historical documentary data, together with other proxy data provide important supplement for increasing the coverage and extending backward.

Wang et al.[5] have established the annual mean temperature of the ten climatological regions of China for the period from 1880—1998. The data sources are listed in table 4. There are five stations in each region (see ref. [5] for details.). The regional series have been added to the average with the consideration of the area weights. It was the first time to set up the series with the complete coverage of all ten regions and their area sizes.

Table 4 Original data sources

Area name	Period		
	1880—1910	1911—1950	1951—1998
1 North East	Ob	TMap	Ob
2 North	Ob	TMap	Ob
3 East	Ob	TMap	Ob
4 South	Ob	TMap	Ob
5 Taiwan	Ob, HD	Ob	Ob
6 Mid. South	HD	TMap	Ob
7 Southwest	HD	TMap	Ob
8 Northwest	Ic	TMap	Ob
9 Xinjiang	Ic	Ic	Ob
10 Tibet	Tr	Ob, Tr	Ob

Ob, observations; TMap, temperature category maps; Tr, tree ring data; Ic, Ice core $\delta^{18}O$; HD, historical document.

The regional mean temperature is obtained by averaging the temperatures from the five stations during the past several decades, but in the late 19th century there were only one station's records available for most regions. The increase of station numbers may significantly change the variance of the regional temperature series. In most of the ten regions, the variance of data in a single station is roughly close to that of the average regional data. However, the standard deviation of region 5 is 0.26, but that of Taibei located in the north of Taiwan is 0.39. For the regions 4 and 8, the standard deviation ratios of regional data to the single centeral station data were 0.76 and 0.77 respectively (cf. the period of 1961—1990). We convert the temperature anomaly of a single station to the regional average by multiplying it by their standard deviation ratio when there is only single station data available in the earlier time. In regard to the accordance of method, this multiplication is applied to all regions. The proxies also are converted to the temperature series with the same variance of observed temperatures. The uncertainty could still exist in the series, however, this series may be the one with the best coverage.

The temperature trends of the last century appraised by some previous studies using less temperature data with incomplete coverage are much lower than the global mean (for example, the series by Wang[21] using the data of four stations located in eastern China shows a trend of only +0.09℃/100 a). But as shown in fig. 4, one of the most apparent features is the strong warming trend. The linear trend of the annual temperatures of China with the complete coverage is 0.50℃/100 a. This remarkable warming trend is more obvious than ever estimated before, and is comparable to the global mean trend of 0.5—0.6℃/100 a. The temperature correlation between the global mean and that in China is 0.60 for the last 119 years. This illustrates good parallelism of the warming in China and the world[22,23].

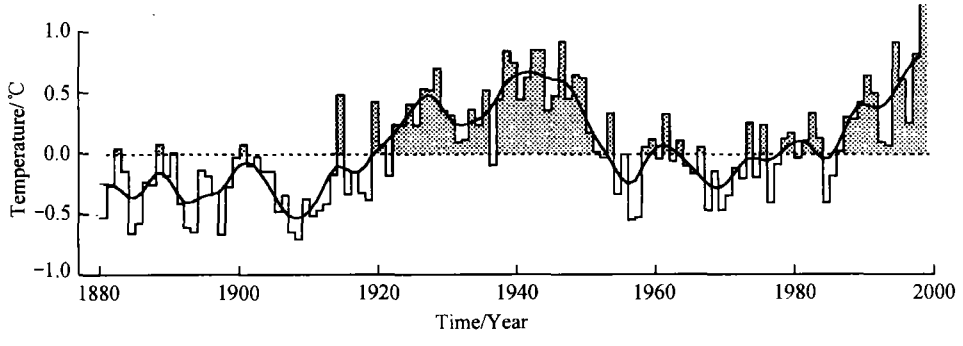

Fig. 4. Annual mean temperature anomalies of China. Reference period is 1961—1990.

It is of interest to notice that the year 1998 can be considered as the warmest year since 1880 in China. The temperature anomaly in 1998 is +1.38℃ (cf. the 1961—1990 mean). The second warmest year occurred in 1946 when the temperature anomaly was +0.92℃, considering even an uncertainty of ±0.16℃, the possible range was 0.76—1.08℃, also lower than +1.38℃. The annual average temperature of 1998 set the highest record for this century in China. This warming may be related to the enhancement of the greenhouse effect.

5 Concluding remarks

The reconstruction of the paleo-climate records relies greatly on the proxy data. However, the proxy data contain a great deal of uncertainties resulting from (i) the representativeness of sample sites, (ii) the precision of dating, and (iii) the error in calibration. These uncertainties do exist in all the data obtained from pollen, ice core $\delta^{18}O$, tree ring and historical documents. Both new proxy data and advanced technology of calibration will promote the work of paleoclimate reconstruction in China.

References

1 Shi, Y. F., *The Climate and Environment of China in the Megathermal* (in Chinese), Beijing: Ocean Press, 1992, 1—212.
2 Zhu, K. Z., Preliminary study on the climatic change in China during the last five thousand years, *Science in China* (in Chinese), 1973, 16(2): 226.
3 Zhang, Y., *Climatic Change and Its Effects* (in Chinese), Beijing: Meteorological Press, 1993 ,57—69, 91—107.
4 Shi, Y. F., Zhang, P. Y., *Historical Climate Changes in China* (in Chinese), Jinan: Shandong Science and Technology Press, 1996, 1—533.
5 Wang, S. W., Ye, J. L., Gong, D. Y. et al., Reconstruction of the temperature series in China for the last one hundred years, *Quarterly Journal of Applied Meteorology* (in Chinese), 1998, 9(4): 392.
6 Gong, G. F., Jian, W. M., The geographical distribution of the vegetation phenology in China, *Acta Geographic Sinica* (in Chinese), 1983, 38(1): 33.
7 Zhang, D., Evidence for the existence of the Medieval Warm Period in China, *Climatic Change*, 1994, 26(2—3): 287.
8 Wang, S. W., Winter and summer temperature of China in the last one thousand years, *Meteorological Monthly* (in Chinese), 1990, 16(6): 15.
9 Wen, H. R., Wen, R. S., *Historical Climate Change for the Winter Half Year in China* (in Chinese), Beijing: Science Press, 1996, 1—167.
10 Gao, X. W., *History of the Natural Disasters in China* (in Chinese), Beijing: Seismic Press, 1997, 1—525.
11 Man, Z. M., Climate in Tang Dynasty of China: discussion for its evidence, *Quaternary Sciences* (in Chinese), 1998, 1: 20.
12 Deng, H., Reconstruction of climatic series of the northern Yanshan Mountains region in Liao Dynasty, *Quaternary Sciences* (in Chinese), 1998, 1: 46.
13 Wang, S. W., Ye, J. L., Gong, D. Y., Climate in China during the Little Ice Age, *Quaternary Sciences* (in Chinese), 1998, 1: 54.
14 Yao, T. D., Xie, Z. C., Records of the Little Ice Age in the Dunde ice core data, *Science in China* (in Chinese), Ser. B, 1990, 11: 1197.
15 Yao, T. D., Yang, Z. H., Huang, C. L. et al., Preliminary research on the climatic and environmental changes by using the 2Ka Guliya ice core data, *Chinese Science Bulletin* (in Chinese), 1996, 41(12): 1103.
16 Kang, X. C., Graumlich, L. J., Sheppard, P., Climatic change in Dulan of Qinghai Province since 1835 A.D.: tree ring data evidence, *Quaternary Sciences* (in Chinese), 1997, 1: 70.
17 Lamb, H. H., *Climatic History and the Future*, *Climate: Present, Past and Future* Vol 2, London: Methuen and Co. Ltd., 1972, 835.
18 Wang, S. W., Reconstruction of the temperature series of northern China back to 1380A.D., *Science in China* (in Chinese), Ser. B, 1990, 5: 553.
19 Zhang, X. G., Zhao, Z., Xu, R. Y., Tree rings of Qilian Mountain and the climatic change in China, in *Proceedings of the Workshop on the Climatic Changes in China* (in Chinese), Beijing: Science Press, 1978, 26.
20 Lin, X. C., Yu, S. Q., Tang, G. L., Temperature series of China in the last one hundred years, *Atmospheric Sciences* (in Chinese), 1995, 19(5): 525.
21 Wang, S. W., Variations of temperature in China for the 100 year period in comparison with global temperatures, *Meteorological Monthly* (in Chinese), 1990, 16(2): 11.
22 Gong, D. Y., Wang, S. W., 1998: The warmest year on record in China during the past century, *Meteorological Monthly* (in Chinese), 1999, 25(8): 1.
23 Wang, S. W., Gong, D. Y., The enhancement of the warming trend in China. *Geophysical Research Letters*, 1999, in press.