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CLIMATIC VARIATIONS IN CHINA OVER THE LAST 2000 YEARS

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ABSTRACT: A compilation of paleoclimate records from ice core, tree-rings, lake sediments and historical documents provides a view of temperature change in China over the recent 2000 years. For all-China temperature reconstruction, six sub-stages are identified for the last two millennia. Around AD 0 - 240, AD 800 - 1100, AD 1320 - 1400 and the period from AD 1880 on were warm while around AD 240 - 800, AD 1100 - 1320, AD 1400 - 1880 were cold. Also, temperature varied from region to region in each of the warm or cold periods. The Eastern Han warm period (0 - AD 240), the cold period covering the span of Wei, Jin, and the Southern and Northern Dynasties, the MWP (AD 800 - 1100) and succeeding LIA occurred in eastern China and the Qilian Mountains. Only the first two climatic events were recorded in Guliya ice core while the so-called MWP and LIA was far weaker. Also, the warming between AD 800 and 1100 didn't occur in the south of Xizang (Tibet) Plateau. Instead, the southern Xizang Plateau experienced warming in AD 1150 - 1400. The aggregated China temperature agrees well with North-hemisphere temperature in the past millennia, indicating close relationship of temperature changes between China and North-hemisphere.

KEY WORDS: climatic variations; the last two millennia; China

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1 INTRODUCTION

In the last years, evidence for climate changes showed that the timing of the two great climatic events of "Medieval Warm Period" (MWP) and "Little Ice Age" (LIA) differed geographically (HUGHES *et al.*, 1994, JONES and BRADLEY, 1992). In other words, the cold or warm periods in one region were often not coincident with those in other regions. The Northern Hemisphere warmth degree in the Middle Ages was lower than or at most comparable to that in the mid-20th-century and the average temperature during the Middle Ages was higher than that during the LIA of the last 1000 years (MANN *et al.*, 1999, CROWLEY and LOWERY, 2000, JONES *et al.*, 1998, BRIFFA, 2000). However, what are the excursion characteristics of the so-called MWP and LIA in China? How did temperature over the first 1000 years of the past two millennia fluctuate? Although many climate reconstructions extending over 1000 or 2000 years have been done for many parts of China, little work has been carried out on combined analysis of all sorts of proxy data. In order to enhance the understanding of climatic changes in China, it is essential to conduct compre-

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hensive comparison and analysis based on previous work. In this article, we chose 9 most reliable proxy temperature series from current proxy records in China and reconstruct a composite temperature series to study basic temperature variation characteristics in China of the recent 2000 years.

2 DATA AND METHOD

The statistics and distribution features of 9 proxy records are demonstrated in Fig. 1 and Table 1. Among them, 4 of 9 reconstructions are derived from Xizang Plateau. They are composed of Guliya ice core $\delta^{18}O$ record in the western Kunlun Mountains, Dulan tree ring width record in the Qilian Mountains, Dunde ice core $\delta^{18}O$ record and temperature grades conversed by tree-ring width in southern Xizang Plateau. It is noted that there are no available data from the seventh to eleventh century in the temperature series of southern Xizang Plateau. For Dunde ice core, because the sample numbers in core 1 and core 3 which are used to measure $\delta^{18}O$ value are different (the former is 3280 samples, and the latter is 7045 samples), there exist some discrepancies in the two $\delta^{18}O$ curves. Here we adopted the averages of $\delta^{18}O$ values measured from core 1 and 3. The other 5 proxy records come from eastern China and adjacent Japan, including temperature reconstruction for eastern China, tree ring $\delta^{13}C$ record for southern Japan, the total organic carbon and C/N records from Great Ghost Lake and Jiaming Lake in southern Taiwan. Among them, the eastern China is rich in historical and documentary sources of climate information for the last two millennia. The temperature reconstruction for eastern China used in this paper are from regions east of 100°E, which has been improved dramatically on the basis of ZHU Ke-zhen (1973) temperature reconstruction. All the proxy data provide a valid temperature representation. The temperature record for eastern China was basically a winter temperature index, while lake record was estimate of growing-season temperatures. The tree ring indices from Dulan area and the southern Xizang Plateau correlated well with measured autumn and summer temperature respectively while $\delta^{18}O$ records in ice core might be good indicator of summer temperature. In addition, the tree ring records from Japan depended on measured $\delta^{13}C$ values. For the limit of resolution of proxy data used in this paper, decadal means of temperature are conducted in this study. For coarse-resolution lake data, we interpolated them into decade by a spline function. To

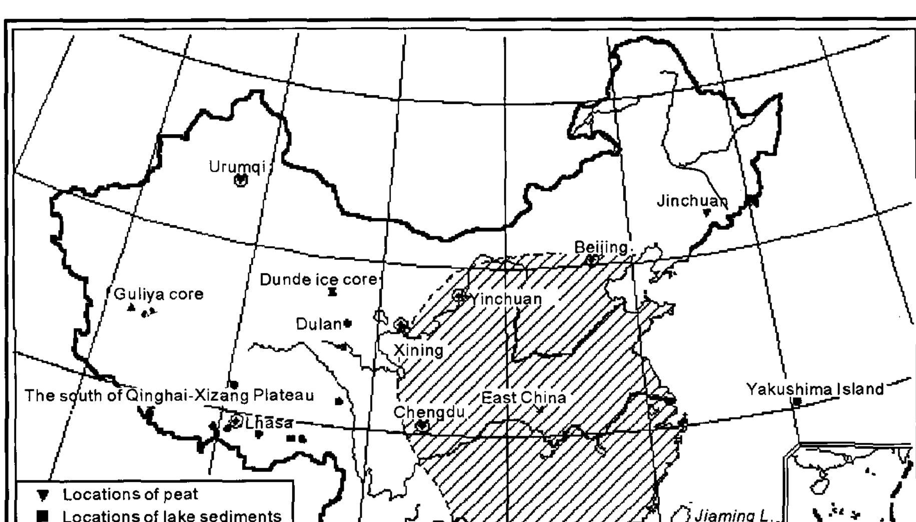

Fig. 1 Diagrammatic sketch showing locations of proxy climate records listed in Table 1

ome extent, the multiplicity of proxy data may be iewed as a sensibility test for reliability of temperature hanges of the last two millennia.

Because of dating uncertainty for lake sediment ecords and peat data, as well as far-away location of uliya ice core, we reconstructed three composite emperature series. The first composite series was alled "summary" aggregated temperature, which excluded lake and peat data. The second series was amed as "full" aggregated temperature, which included all 9 proxy records. The final series was "basic" ggregated temperature, which was exclusive of Guliya e core $\delta^{18}O$ record. Some studies showed that primary haracteristics of large-scale climatic change can comonly be reproduced by way of using little heterogeeous data set (JONES *et al.*, 1999; CROWLEY and OWERY, 2000) . According to this hypothesis, 9 econstructed temperature series from China and its icinity were chosen. Fig. 2 shows the curves of 9 proxy ecords and Table 1 gives data sources of these records. ach proxy temperature series has been standardized espectively so as to scale original variance of all series ver a common base. By these procedures above, each roxy record can not provide specific value of temperture variations but indicates relative magnitude.

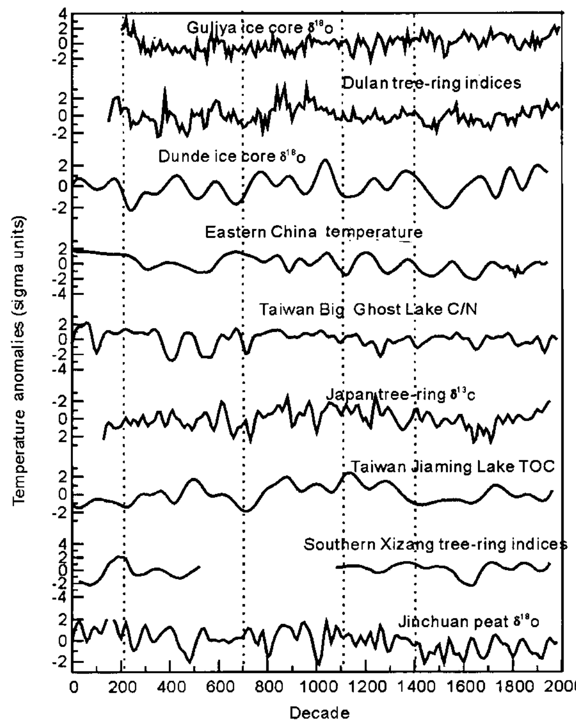

Fig. 2 Standardized 2000-year proxy climate records reflecting surface air temperature for sites from all of China (Fig. 1 and Table 1)

Table 1 The characteristics of proxy temperature data in China and its vicinity

No.	Resolution	Site name	Proxy type	Source
1	20 – 30a	Biwa Lake in central Japan	Total carbon	INOOUCHI *et al.*, 1995
2	Annual – decadal	Suigetsu Lake in central Japan	Quartz/illite	FUKUSAWA, 1995
3	Decade	Yakushima Island in southern Japan	Tree ring $\delta^{13}C$	KITAGAWA, 1995
4	20a	Great Ghost Lake in southern Taiwan	Total carbon	LOU *et al.*, 1997
5	20a	Jiaming Lake in southern Taiwan	C/N ratio	LOU and CHEN, 1997
6	Decade	Guliya in western Kunlun Mountains	Ice core $\delta^{18}O$	YAO *et al.*, 1996; SHI *et al.*, 1999
7	50a	Dunde in Qilian Mountains	Ice core $\delta^{18}O$	THOMPSON *et al.*, 1993
8	Annual	Dulan in Qilian Mountains	Tree ring widths	KANG, *et al.*, 1997
9	Interdecadal	Eastern China	Documents	ZHANG *et al.*, 1996
10	20a	Jinchuan in Northeast China	Peat $\delta^{18}O$	HONG *et al.*, 2000
11	Annual	Southern Xizang Plateau	Tree ring widths	WU and LIN, 1981

RESULTS AND ANALYSIS

Fig. 3 reveals temperature changes in China and orthern Hemisphere. Among them, the MANN *et al.* (1999) reconstruction was determined by regressing an empirical orthogonal function analysis of the 20th century mean annual temperatures against various proxy indices, which has a varying number of records per unit of time. The CROWLEY and LOWERY (2000) reconstruction is based on a more heterogeneous mix of data, but the number of records is nearly constant in time. Here we adopted standardized decadal average values of MANN *et al.* and CROWLEY and LOWERY reconstructions. The Eurasian temperature reconstruction (smoothed with 50a Gaussian filter) is based on averaging three 2000-year-long tree ring width chronologies, which was calibrated against the April – September mean temperature for all land north of 20°N (BRIFFA, 2000). As shown in Fig. 3, temperature fluctuations over three aggregated China temperature series show good agreement, particularly in those large peak-valley values. The correlation coefficients of "full" aggregated series with "basic" and "summary" aggregated series are 0. 92 and 0. 76 respectively, which far exceed significance level of 0. 001. This provides further support for the view that heterogeneous paleoclimatic data set with a small amount can obtain reliable estimates of large-scale temperature variations. Recently, WANG and GONG (2000) divided Chinese territory into ten regions according to inter-correlation among the 1° × 1° latitude × longitude mean temperature records. It provided another way for reconstruction of temperature series in China for the last two millennia. In other words, temperature reconstruction should be based on proxy record of each region and its area weight. Given that the data sources for temperature reconstruction of eastern China cover the most east continent of China, including North, East, South, Middle and Southwest China, its area weight was the sum (i. e., 0. 329) of the weights of the five region above. Dunde and Guliya ice core adopted the area weights (0. 198 and 0. 149) of Northwest China and Xinjiang, and Dulan tree ring and Jinchuan peat used the weights (0. 182 and 0. 131) of Xizang and Northeast China respectively. For Taiwan, we computed the average of the temperature reconstructions of Great Ghost Lake and Jiaming Lake and used the area weight (0. 011) of Southeast China. Thus we established another temperature series for all of China (Fig. 3b) and made a comparison with "full" temperature series for China above (Fig. 3). As shown in Fig. 3, the two curves showed good agreement. They all seem to show distinct warmth in AD 0 – 240, AD 800 – 1100, around AD 1400 and the 20th century. Also, their correlation coefficient (0. 79, $n = 196$) by far exceeds the significance level of 0. 001. This further shows the reliability of the temperature reconstructions.

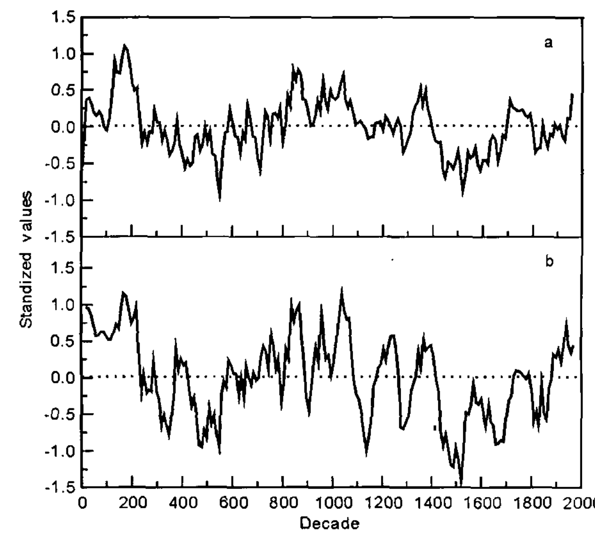

Fig. Fig. 3 Comparison of "weighted" and "full" temperature reconstruction series for China

Curve a is calculated using the way of CROWLEY and LOWERY (2000), and curve b using the way of WANG and GONG (2000)

In the following, taking "full" aggregated temperature series as an example, we make clear the outlines of temperature evolution in China of the last 2000 years. As shown in Fig. 3, this period of AD 0 – 240 (in the Eastern Han Dynasty warm period) was warm, and the warming peak around AD 200 was the warmest of the last two millennia. In this case, 7 of 9 proxy records were characterized by warmth. In other words, this warming were found both in East China and Northwest China. Then temperature dropped with some fluctuations and continued till AD 800. Except from Jinchuan peat, the rest proxy records showed apparent cooling. This cooling period was called as Kofun Cold Stage in Japan (SAKAGUCHI, 1983). From AD 800 on, temperature rose and last until AD 1100. Authors thought this warming period from AD 800 to AD 1100 corresponded to the so-called Medieval Warm Period (HUGHES and DIAZ, 1994). In Japan, FUKUSAWA

(1995) considered AD 740 – 1080 as corresponding MWP. But there are some differences in phase compared with China. In those 9 records, Guliya ice core $\delta^{18}O$ was characterized by cooling. There was a lack of tree ring data in WU *et al.* (1981) tree-ring curve but lake sediments indicated that this period (AD 800 – 1100) witnessed colling in this area. In addition, new evidence shows that southern Xizang Plateau edperienced a warming between AD 1150 and 1400 (BRAEUNING, 1999). Remarkable warm periods occurred in the rest sites. Afterwards, temperature decreased till AD 1320. Among 9 proxy data, 4 records represented obvious cold period, which were mainly located in West China. To our attention, ZHANG curve (1996) showed that eastern China experienced one warm interval around 13th century, which also was found by ZHANG (1994). Around AD 1320 – 1400 was warm and proxy data except Jiaming Lake were characteristic of warmth. From AD 1400 China entered the so-called LIA. The LIA continued till AD 1880 with a warm interval of AD 1700 – 1800 occurred in all 9 proxy data. Except Guliya ice core, this cold LIA stage existed in other proxy records. The former cooling stage (AD 1400 – 1700) was much colder compared with the latter cooling stage (AD 1800 – 1880). After the LIA ended, the modern warming period came. Give a lack of proxy data for this period, here we didn't conduct detailed discussion.

As shown in Fig. 4, around AD 240, AD 800, AD 1100, AD 1320, AD 1400 and AD 1880 were transition periods of temperature change in China during the last 2000 years. On the other hand, on decadal time scale, there is a significant positive correlation between all China "full" integrated temperature and Northern Hemisphere temperature reconstructions of JONES *et al.* (1998) and of MANN *et al.* (1999) over the last 1000 years. Their correlation coefficients are 0.42 and 0.32 ($R_{0.01}=0.26$), respectively. There are many common characteristics in the above temperature reconstructions. For example, the warm periods around AD 1000 and AD 1350 and succeeding LIA, the warmth around AD 1700 – 1800 and succeeding cooling period, as well as the 20th-century warming. However, it appears that the temperature variations for all of China lead that of Northern Hemisphere. Maximum correlation coefficients of 0.55 and 0.40 are found when "full" all China temperature lags Northern Hemisphere temperature records by 30 – 40 years. Also, measured temperature data indicated that the warmest interval of the 1940s in China was earlier than that of 1980s in Northern Hemisphere (LIN *et al.*, 1995). Further evidence is needed to support this hypothesis. Furthermore, the all China proxy temperature series compares better with Northern Hemisphere temperature reconstruction of JONES *et al.* (1998)

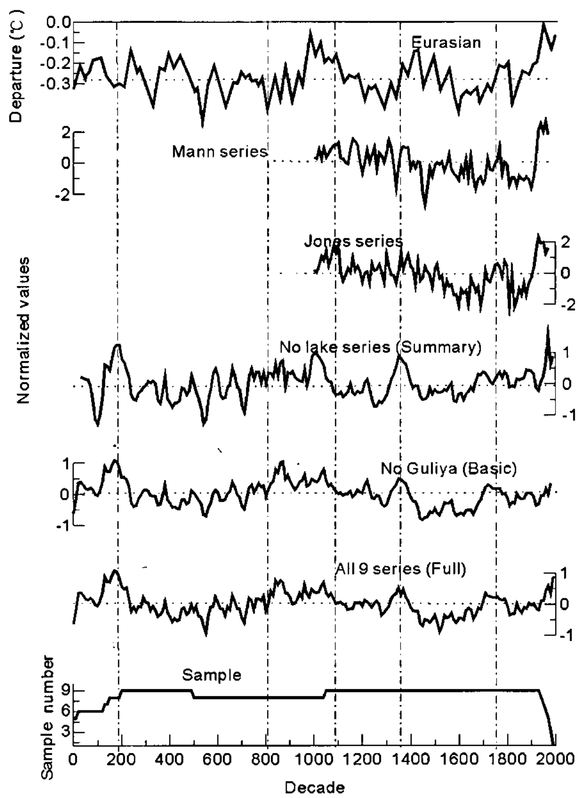

Fig. 4 Comparison of the composite temperature in China with Northern Hemisphere temperature reconstructions in the last two millennia (MANN *et al.*, 1999; JONES *et al.*, 1998; BRIFFFA, 2000)

compared with the reconstruction of MANN *et al.* (1999). In addition, the correlation coefficient between the weighted China temperature reconstruction and Northern Hemisphere temperature series of JONES *et al.* (1998) is 0.49. All these facts suggest that there is a close association between temperature in China and Northern Hemisphere.

4 DISCUSSION

It has been possible to assemble available proxy climatic data to provide a complete view of China temperature variability over the last two millennia. Confined to original proxy data, we have studied decadal climatic changes in China alone. Results show that three reconstructed all China temperature series coincide very well with each other. This suggests that heterogeneous paleoclimatic data set with a little amount may provide a valid representation of regional climatic change. On the other hand, comparison of the composite temperature for all of China with reconstructed Northern Hemisphere temperature of the last millenium suggests that the former appear to lead the latter by 40 years or so. Another fact is noted that the warming period AD 800 – 1100 in China was earlier than that in AD 1100 – 1300 occurred in Central England (LAMB, 1965). Does the answers are affirmative, what is the physical mechanism relating the variables? The correlation in Fig. 4 suggests that it is important to search for answers to these questions. Since climate reconstructions extending over 1000 or 2000 years have been done for many parts of the world, it would be instructive to analyze their relationships, and to understand the underlying physical mechanism.

REFERENCES

BRADLEY R S, JONES P D, 1993. 'Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends [J]. *The Holocene*, 3: 367 – 376.

BRAEUNING A, 1999. Zur Dendroklimatologie Hochtibets wahrend des letzten Jahrtausends[C] . Dissertationes Botanicae.

BRIFFA K R, 2000. Annual climate variability in the Holocene: interpreting the message of ancient trees [J]. *Quaternary Science Reviews*, 19: 87 – 105.

CROWLEY T J, LOWERY T S, 2000. How warm was the Medieval Warm Period [J]. *Ambio*, 29(1): 51 – 54.

FUKUSAWA H, 1995. High-resolution reconstruction of environmental changes from the last 2000 years varied sediments in Lake Suigetsu central Japan [A]. In: *Paleoclimate and Environmental Variability in Austral-AsianTransect during the Past 2000 Years*[C], (Proceedings of the 1995 Nagoya IGBP-PAGES/PEP-II Symposium) Nagoya University. Nagoya, Japan , 84 – 89.

HONG Ye-tang, JIANG Hong-bo *et al.*, 2000. Response of climate to solar forcing recorded in a 6000-year $\delta^{18}O$ time-series of Chinese peat cellulose [J]. *The Holocene*, 10(1): 1 – 7.

HUGHES M K, DIAZ H F, 1994. Was there a 'Medieval Warm Period', and if so, where and when [J]. *Climatic Change*, 26(2): 109 – 142.

INOUCHI Y, YOKOTA S, TERASHIMA S, 1995. Climatic changes around Lake Biwa during the past 300 000 years and 2000 years [A] . In: *Paleoclimate and Environmental variability in Austral-Asian Transect during the Past 2000 Years* [C] (Proceedings of the 1995 Nagoya IGBP-PAGES/PEP-II Symposium). Nagoya University, Nagoya, Japan, 109 – 114.

JONES P D, BRADLEY R S, 1992. Climatic variations over the last 500 years [A] . In: BRADLEY R S, JONES P D (eds.). *Climate since A. D. 1500* [C]. London: Routledge, 649 – 665.

JONES P D, BRIFFA K R, Barnett T P *et al.*, 1998. High-resolution palaeoclimatic records for the last millennium: Interpretation, integration and comparison with General Circulation Model control-run temperatures [J] . *The Holocene*, 8: 455 – 471.

JONES P D, OSBORN T J, BRIFFA K R, 1999. Estimating sampling errors in larger-scale temperature averages [J]. *Journal of Climate*, 10: 2548 – 2568.

KANG Xing-cheng, GRAUMLICH L J, SHEPPARD P R, 1997. The last 1835 years climate changes inferred from tree ring records in Dulan region, Qinghai, China [J]. *Quaternary Sciences*, 1: 70 – 75.

KITAGAWA H, 1995. Climatic implications in a Japanese cedar (Crhptomeria Japonica) during the last two millennia [J] . *Geophys. Res. Lett.*, 22(16): 2155 – 2188.

LAMB H H, 1965. The early Medieval Warm Epoch and its sequel [J] . *Palaeogeography, Palaeoclimatology, Palaeoecology*, 1: 13 – 37.

LIN Xue-chun, Yu Shu-qiu, TANG Guo-li, 1995. Series of average air temperature over China for the last 100-year period [J]. *Scientia Atmospherica Sinica*, 19(5): 525 – 534. (in Chinese)

Lou Jian-yu, CHEN Zheng-dong, WANN J K, 1997. Paleoclimatological records of Great Ghost Lake in Taiwan[J] . *Science in China (Series D)*, 40(3): 284 – 292.

Lou Jian-yu, CHEN Zheng-dong, 1997. Paleoclimatological and paleoenvironmental records since 4000 a B. P. in the sediments of alpine lakes in Taiwan [J]. *Science in China (Series*

D), 40(4): 424 - 431.

MANN M E, BRADLEY R S, HUGHES M K, 1999. Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations [J]. *Geophys. Res. Lett.*, 26: 759 - 762.

OVERPECK J, HUGHEN K, HARDY D, *et al.*, 1997. Arctic environmental changes of the last four centuries [J]. *Nature*, 278(5341): 1251 - 1256.

SAKAGUCHI Y, 1983. Warm and cold stages in the past 7600 years in Japan and their global correlation — Especially on climatic to the global sea level changes and the ancient Japanese history [J]. *Bulletin of Department of Geography, University of Tokyo,* 15: 1 - 31.

SHI Ya-feng, YAO Tan-dong, YANG Bao, 1999. Decadal climatic variations recorded in Guliya ice core and comparison with the historical documentary data from East China during the last 2000 years [J]. *Science in China (Series D),* 42 (Supplement): 91 - 100.

TANG Lin-yu, SHEN Cai-ming, LIU Kam-biu *et al.*, 2000. Changes in south Asian monsoon: New high-resolution paleoclimatic records from Tibet, China [J]. *Chinese Science Bulletin,* 1: 87 - 91.

THOMPSON L G, MOSLEY-THOMPSON E, DAVIS M E *et al.*, 1993. Recent Warming: Ice core evidence from tropical ice cores with emphasis on Central Asia [J]. *Global Planet. Change,* 7: 145 - 156.

WANG Shao-wa, GONG Dao-yi, 2000. Enhancement of the warming trend in China [J]. *Geophysical Research Letters,* 27 (16): 2581 - 2584.

WU Xiang-ding, LIN Zhen-yao, 1981. Climatic change during the last 2000 years in Tibet [A]. In: *Proceedings of Symposium on Climatic Change*[C]. Beijing: Science Press, 18 - 25. (in Chinese)

YAO Tan-dong, THOMPSON L G, QIN Da-he *et al.*, 1996. Variations in temperature and precipitation in the past 2000 a on the Xizang (Tibet) Plateau—Guliya ice core record [J]. *Science in China (Series D),* 39(4): 459 - 467.

ZHANG De-er, 1994. Evidence for the existence of the Medieval Warm Period in China [J]. *Climate Change,* 3: 289 - 297.

ZHANG Pei-yuan, 1996. *Climate Change in China during Historical Times* [M]. Jinan: Scientific and Technological Press, 435 - 436. (in Chinese)

ZHU Ke-zhen, 1973. A preliminary study on the climatic fluctuations during the last 5 000 years in China [J]. *Scientia Sinica,* 16: 226 - 256.