Variations in temperature and precipitation in the past 2 000 a on the Xizang (Tibet) Plateau —— Guliya ice core record*

YAO Tandong (姚檀栋), L. G. Thompson**, QIN Dahe (秦大河), TIAN Lide (田立德), JIAO Keqin (焦克勤), YANG Zhihong (杨志红) and XIE Chao (谢 超)

(Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou 730000, China)

Received January 30, 1996

Abstract The past temperature and precipitation variations are recorded precisely and continuously in $\delta^{18}O$ and glacial accumulation records in the Guliya ice core. Eight warm periods and seven cold periods can be distinguished in the past 2 000 a. Of the four most intensive cold periods, three are in the Little Ice Age and one in the 11 th—12 th century. The variation of precipitation is relatively small compared with that of temperature. Five humid periods and four dry periods occurred in the past 2 000 a. The long-term variation of temperature is positively correlated with that of precipitation according to the Guliya ice core record, but the variation of precipitation lags behind the variation of temperature.

Keywords: Guliya ice core, $\delta^{18}O$, glacial accumulation.

The study of climatic variations in the past 2 000 a is essential to study the past global change, to detect the present global change and to predict the future global change.

The information about climatic change in the past 2 000 a can be found in some papers. It can be roughly seen from the reconstructed temperature curve in the past 5 000 a, based on historical document by Zhu[1]. On the Xizang Plateau, Wu *et al.*[2] reconstructed the past climatic change by linking different tree rings data from Lhasa.

The characteristic of the Guliya ice core record is that it has recorded not only the change of temperature and precipitation, but also the variation processes of the two indicators with high resolution on the Xizang Plateau.

1 Significance of climatic proxies

The data used in this paper are derived from the second one of the Guliya ice core. Information about the Guliya Ice Cap, ice core drilling and sampling, analysis, temperature and precipitation indices and their significance is discussed elsewhere in detail[3-5].

The temperature record in the Guliya ice core is expressed in $\delta^{18}O$. $\delta^{18}O$ in precipitation

* Project supported by the Climbing Program and the National Natural Science Foundation of China.

** Byrd Polar Research Center, Ohio State University, Columbus, OH43210, USA.

is a reliable indicator of temperature on the northern Xizang Plateau, which has already been verified in the following aspects. Firstly, according to the monitor of $\delta^{18}O$ and temperature change in each precipitation event and the seasonal change of $\delta^{18}O$ and temperature during several years, $\delta^{18}O$ in precipitation is correlated with temperature positively, i.e. low temperature in winter corresponds to low $\delta^{18}O$ value in precipitation and high temperature in summer corresponds to high $\delta^{18}O$ value in precipitation. Secondly, the positive correlation between $\delta^{18}O$ and temperature can be expressed quantitatively. Whenever $\delta^{18}O$ in precipitation increases (or decreases) by 1‰, temperature increases (or decreases) by about 1.6℃, and *vice versa*[5] 1).

The recovery of precipitation in the Guliya Ice Cap is based on the glacial accumulation —— the precipitation in the glacier accumulation area. Of all kinds of glaciers, the glacial accumulation in ice cap is the closest to actual precipitation according to Kotliyakov[7]. As far as the location of the second core of the Guliya ice core is concerned, the glacial accumulation can generally reflect the actual precipitation.

As a temperature index, $\delta^{18}O$ is analysed by MAT-252 mass-spectrometer, with a precision within ±0.5‰. The precipitation index, glacial accumulation, is acquired through counting dirt layers in ice core and calculating by correlation model afterwards, and its precision is ±1%. The variations of temperature and precipitation in the Guliya ice core during the past 2 000 a can be reconstructed annually, so that high resolution time series can be established.

The annual variations of $\delta^{18}O$ and glacial accumulation are smoothed to decadal average in this paper.

2 Results

Figure 1 shows the variations of decadal average temperature ($\delta^{18}O$) and precipitation (glacial accumulation) in the past 2 000 a recorded in the Guliya ice core. The general trend can be seen in fig. 1: the beginning of the first century is a period with low temperature and low precipitation, and thereafter, temperature and precipitation increase with fluctuations. Obviously, temperature and precipitation are correlated positively, which can also be seen in fig. 2. Except for the general trend, the variations of temperature and precipitation are not in the same phase. At first, the frequency of low frequency fluctuations in temperature is higher than that in precipitation. To study this feature, the decadal average variations of temperature and precipitation in the past 2 000 a have been smoothed by 11-point running average (fig. 3). To study the discrepancy of low-frequency variations between temperature and precipitation in detail is of great significance for pre-

1) Yao Tandong *et al.*, The oxygen isotope and its significance to the ice core record in the northern Xizang Plateau, *Journal of Geophysical Research* (in press).

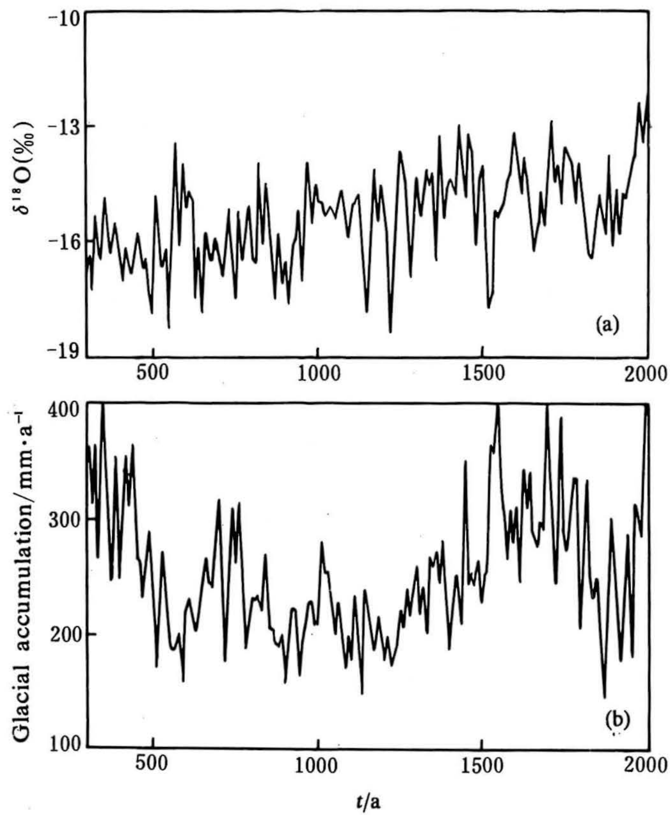

Fig. 1. Variations of $\delta^{18}O$ and glacial accumulation in the past 2 000 a recorded in the Guliya ice core (decadal average).

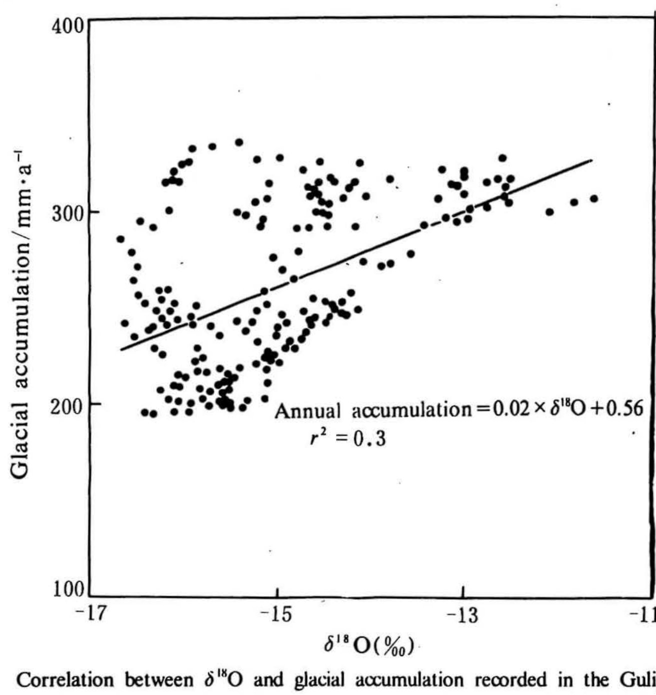

Fig. 2. Correlation between $\delta^{18}O$ and glacial accumulation recorded in the Guliya ice core.

dicting the future dry-humid variations accompanied by temperature variations. According to the variations of temperature and precipitation as shown in fig. 1, 7 cold periods and 8 warm periods can be distinguished (table 1) in the past 2 000 a, but only 4 dry periods and 5 humid periods can be distinguished (table 2). Obviously, the variation frequency of temperature is much higher than that of precipitation. If it is also true in a more extensive sense, it will be also true that there are more cold-warm alternations in the century scale variations, whereas the dry or humid period will last longer.

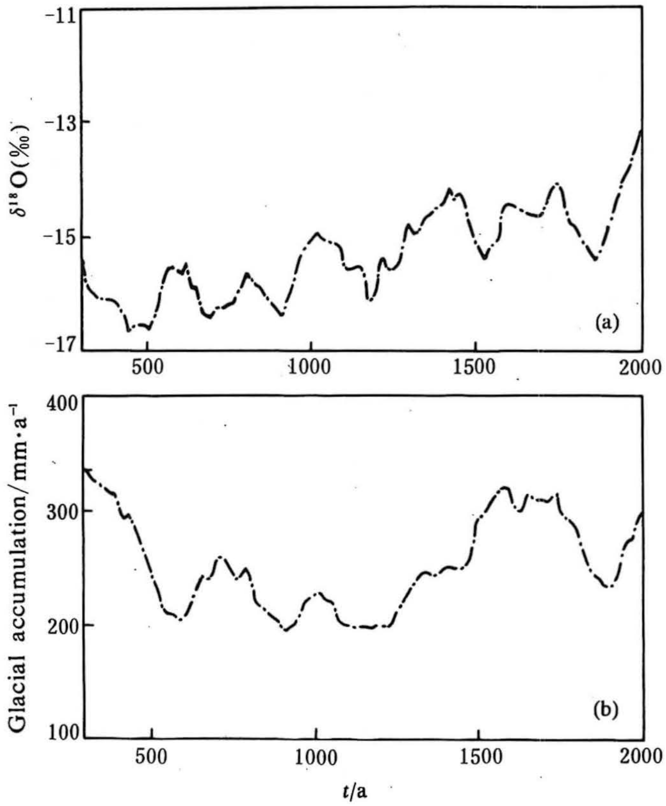

Fig. 3. Eleven-point running average of $\delta^{18}O$ and glacial accumulation to decadal mean in the Guliya ice core.

Table 1 Cold and warm period alternations on century scale

Cold period		Wet period	
Period (A. D.)	Duration/a	Period (A. D.)	Duration/a
		300— 350	50
351— 500	150	500— 600	100
600— 700	100	701— 800	100
801— 900	100	901—1 100	200
1 101—1 200	100	1 201—1 450	250
1 451—1 500	50	1 501—1 600	100
1 601—1 690	90	1 691—1 790	100
1 791—1 880	90	1 880—1 990	110

Table 2 Dry and humid period alternations on century scale

Dry period		Cold period	
Period (A.D.)	Duration/a	Period (A.D.)	Duration/a
		300— 400	100
401— 560	160	561— 720	160
721— 980	260	981—1 080	100
1 081—1 270	190	1 271—1 600	330
1 601—1 640	40	1 641—1 810	170
1 811—1 930	120	1 931—1 990	60

Though low-frequency variations of temperature recorded in the Guliya ice core are more than those of precipitation in the long-term trend, the amplitude of precipitation variations in the individual dry-humid cycle is higher than that of temperature, i. e. the impact of of dryhumid variations on agriculture is more serious than the impact of temperature change.

It can also be seen in fig. 3 that the variations of precipitation lag behind the variations of temperature in the Guliya ice core record, although the dry-humid variations and the cold-warm variations are generally in agreement. The lag is about 50—100 a and this phenomenon occurred in both temperature-increasing periods and temperature-decreasing periods, especially in the temperature-decreasing periods. This phenomenon is probably due to the large specific heat of ocean water, whose reaction lags behind temperature change, which can cause a temporal discrepancy between evaporation intensity and warming intensity and eventually lead to a temporal discrepancy between precipitation and temperature change.

3 Discussion

As shown in the Guliya ice core record, temperature tends to warming gradually and precipitaton tends to increasing in their fluctuations from the beginning of 500 A. D. The variations of cold and warm events recorded in the Guliya ice core are the most detailed records among the available climatic records in the past about 2 000 a. Compared with the past 2 000 a climatic variations in Lhasa region based on the linked tree ring record by Wu Xiangding *et al.*, all the cold periods reflected in the tree ring record can be observed in the Guliya ice core record. For instance, the three cold periods during 300— 500 A. D., 11th—12th century and the well-defined Little Ice Age can all be observed conspicuously in the Guliya ice core record. Nevertheless, some obvious cold periods in the Guliya ice core record do not have any reflection in the tree ring record. For example, the cold periods in about the 9th century and about the 7th century recorded in the Guliya ice core have no sign in the tree ring record, which is probably caused by the discontinuity of tree rings linkage.

After being smoothed by 11-point running average, the $\delta^{18}O$ curve (fig. 4) can be used

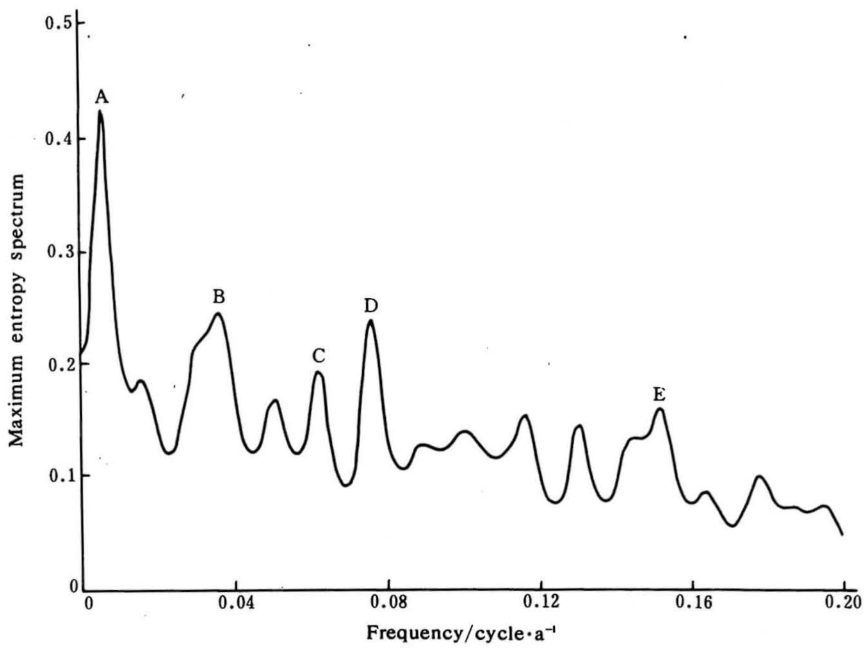

Fig. 4. Maximum entropy spectrum of $\delta^{18}O$ record in the Guliya ice core.

to analyse several intensive cold periods during the past 2 000 a (table 1). There are 7 intensive cold periods in the past 2 000 a, of which the last 3 belong to the Little Ice Age. All the three cold periods have caused glacial advance according to the glaciological study in West China. The previous one is an intensive cold period occurring in the 12th century, which has been discovered in various studies. The cold period occurring during the past 300—500 a can also be found in some studies. However, reports about the two cold periods occurring in around 700 A. D. and 900 A. D. can hardly be found. As shown in fig. 3, the two cold periods are more intensive than the three cold periods in the Little Ice Age, and there should be more obvious glacial advance. It is expected that the remains of the two cold periods will be found somewhere. In addition, the cold period occurring in 300—500 A. D. may also have caused glacial advance, but the cold period occurring during 11th—12th century is so intensive that all the remains left by the previous glacial advance have probably covered by the large-scale glacial advance occurring in this period. As a result, the remains of glacial advance during these cold periods can only be found occasionally. The Guliya ice core record provides proof for the further study of the remains of these cold periods.

The year of 1 100 A. D. is a main turning point. The climate before 1 100 A. D. is characterized by frigidity and less precipitation, and after 1 100 A. D., temperature and precipitation increased.

The abrupt climatic change events are also reflected pronouncedly in the Guliya ice core record. These events occurred not only in the warming periods, but also in the cooling periods. During the cold period of 300—500 A. D., two warming events occurred abruptly. The abrupt shift featured all the warming and cooling events in the two intensive cold periods during the 11th—12th century. The three cold periods in the traditional Little Ice Age are all typical abrupt cooling events. The abrupt shift of precipitation in the record is also obvious, though it has nothing to do with abrupt temperature change.

From the climate oscillation in the past 2 000 a, we can see that the present period is the warmest period in the past 2 000 a. A cold period must follow a warm period in the past 2 000 a record, and the continuous warm period like the present one can only be found in about 600 A. D. Therefore, the trend of climatic change in future is essential not only practically, but also theoretically. In other word, the question whether the impact of human activities on climatic system has already changed the natural process of climate change may possibly be answered in the future ice core study. If the temperature record in ice core keeps on increasing in the near future, it is reasonable to believe that the impact of human activities has already changed the natural trend of climatic change. Otherwise, a new cold period is impending.

Through the analyses of the frequency of the Guliya ice core record, the difference between the long-term change trends of temperature and precipitation can be observed. Maximum entropy spectrum analysis has been applied to the temperature and precipitation record in this paper. There are 5 obvious frequencies in the maximum entropy spectrum of temperature: 200-a cycle (peak A), 21-a cycle (peak B), 15-a cycle (peak C), 11-a cycle (peak D) and 6-a cycle (peak E) (fig. 4). There are also 5 frequencies in the maximum entropy spectrum of precipitation: 200-a cycle (peak A), 15-a cycle (peak B), 14-a cycle (peak C), 11-a cycle

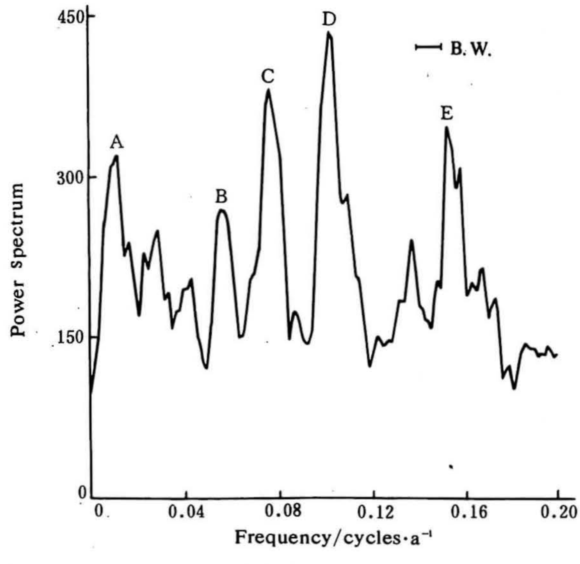

Fig. 5. Maximum entropy spectrum of glacial accumulation record in the Guliya ice core.

(peak D) and 6-a cycle (peak E)(fig. 5). Comparing the two entropy spectra, we can find that the cycles of the two indices are generally in agreement except for the lack of 21-a cycle and an excess of 14-a cycle in precipitation record. Furthermore, there is no much difference between the 14-a cycle and the 15-a cycle. Except the 6-a cycle which is close to ENSO cycle, all the above cycles are generally related to solar activity. For example, the 11-a cycle is the well-known sunspot activity cycle, the 21-a cycle is close to the 22-a Hale cycle, and the 200-a cycle is also called bicentenary cycle. Therefore, the temperature and precipitation records in the Guliya ice core are closely related to the solar activity.

4 Conclusions

The temperature and precipitation variations recorded in the Guliya ice core provide a detailed pattern of climatic change in the past 2 000 a on the Xizang Plateau. Eight warmer periods and seven colder periods can be distinguished in the past 2 000 a, and the coldest period is the 11th — 12th century. The three cold periods in the Little Ice Age caused extensive glacial advance in West China, but they were not extremely cold compared with the other cold periods in the past 2 000 a. There are 5 relatively high-precipitation periods and 4 relatively low-precipitation periods in the past 2 000 a. The fluctuations in precipitation are less than those of temperature, i.e. some fluctuations of temperature did not affect precipitation.

In the past 2 000 a, except for the high-temperature and high-precipitation period before 500 A. D., both temperature and precipitation show an increasing trend with fluctuations from 500 A. D. to present. In the general increasing trends, they fluctuate in different ways. The frequency of low-frequency fluctuation of temperature is higher than that of precipitation. The variation of precipitation lags behind the variation of temperature although their general variations correspond with each other on the whole. The lag time is 50 — 100 a, i. e. the peak of precipitation comes only 50 — 100 a later after the peak of temperature.

References

1 Zhu Kezhen, Preliminary study on the climate variations of the last 5 000 a in China, *Science in China* (in Chinese), Ser. B, 1973, (2): 291.

2 Wu Xiangding, Lin Zhenyao, Preliminary study on the climate variations in the past 2 000 a on the Qinghai-Tibetan Plateau, in *Proceedings of the National Climatic Change Conference* (in Chinese), 1981, Beijing: Science Press, 18—25.

3 Yao Tandong, Jiao Keqin, Tian Lide *et al.*, Climatic and environmental records in Guliya Ice Cap, *Science in China*, Ser. B, 1995, 38(2): 228.

4 Yao Tandong, Jiao Keqin, Yang Zhihong *et al.*, Little Ice Age recorded in Guliya Ice Core, *Science in China* (in Chinese), Ser. B, 1995, 25(10): 1108.

(peak D) and 6-a cycle (peak E)(fig. 5). Comparing the two entropy spectra, we can find that the cycles of the two indices are generally in agreement except for the lack of 21-a cycle and an excess of 14-a cycle in precipitation record. Furthermore, there is no much difference between the 14-a cycle and the 15-a cycle. Except the 6-a cycle which is close to ENSO cycle, all the above cycles are generally related to solar activity. For example, the 11-a cycle is the well-known sunspot activity cycle, the 21-a cycle is close to the 22-a Hale cycle, and the 200-a cycle is also called bicentenary cycle. Therefore, the temperature and precipitation records in the Guliya ice core are closely related to the solar activity.

4 Conclusions

The temperature and precipitation variations recorded in the Guliya ice core provide a detailed pattern of climatic change in the past 2 000 a on the Xizang Plateau. Eight warmer periods and seven colder periods can be distinguished in the past 2 000 a, and the coldest period is the 11th — 12th century. The three cold periods in the Little Ice Age caused extensive glacial advance in West China, but they were not extremely cold compared with the other cold periods in the past 2 000 a. There are 5 relatively high-precipitation periods and 4 relatively low-precipitation periods in the past 2 000 a. The fluctuations in precipitation are less than those of temperature, i.e. some fluctuations of temperature did not affect precipitation.

In the past 2 000 a, except for the high-temperature and high-precipitation period before 500 A. D., both temperature and precipitation show an increasing trend with fluctuations from 500 A. D. to present. In the general increasing trends, they fluctuate in different ways. The frequency of low-frequency fluctuation of temperature is higher than that of precipitation. The variation of precipitation lags behind the variation of temperature although their general variations correspond with each other on the whole. The lag time is 50 — 100 a, i. e. the peak of precipitation comes only 50 — 100 a later after the peak of temperature.

References

1 Zhu Kezhen, Preliminary study on the climate variations of the last 5 000 a in China, *Science in China* (in Chinese), Ser. B, 1973, (2): 291.

2 Wu Xiangding, Lin Zhenyao, Preliminary study on the climate variations in the past 2 000 a on the Qinghai-Tibetan Plateau, in *Proceedings of the National Climatic Change Conference* (in Chinese), 1981, Beijing: Science Press, 18—25.

3 Yao Tandong, Jiao Keqin, Tian Lide *et al.*, Climatic and environmental records in Guliya Ice Cap, *Science in China*, Ser. B, 1995, 38(2): 228.

4 Yao Tandong, Jiao Keqin, Yang Zhihong *et al.*, Little Ice Age recorded in Guliya Ice Core, *Science in China* (in Chinese), Ser. B, 1995, 25(10): 1108.

5 Yao Tandong, Thompson, L G., Jiao Keqin *et al.*, Climatic warming as recorded in Tibetan cryosphere, *Annals of Glaciology*, 1996, 21: 196.

6 Li Zhongqin, Yao Tandong, Huang Cuilan *et al.*, Characteristic of chemical substance deposition and record of present atmospheric environment in the Guliya Ice Core, in *Annual of the Development and Evolution, Environment Variations and Biosystem on the Qinghai-Tibetan Plateau* (in Chinese)(1994), Beijing: Science Press, 1995, 11—21.

7 Kotliyakob, V. M., Krenu, A. N., Investigation of the hydrological conditions of alpine regions by glaciological methods, *IAHS*, 1982, 138: 31.