DISCUSSIONS

Amplitude of climatic changes in Qinghai-Tibetan Plateau

YAO Tandong [1], LIU Xiaodong [2], WANG Ninglian[1] & SHI Yafeng[1]

1. Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou 730000, China;
2. Lanzhou Institute of Atmospheric Physics Over Highlands, Chinese Academy of Sciences, Lanzhou 73000, China

Abstract On the basis of ice core and meteorological data from the Qinghai-Tibetan (Q-T) Plateau, this article focuses on the discussion of the problems related to the sensitivity of temporal and spatial changes of the climate in high-altitude regions, particularly in the Q-T Plateau. The features of abrupt climatic changes of the past 100 ka, 2 000 a and recent years indicate that the amplitude of these changes in the Q-T Plateau was obviously larger than that in low-altitude regions. The scope of temperature change above 6 000 m in the Q-T Plateau between glacial and interglacial stages could reach over 10℃, but only about 4℃ in low-elevation regions close to sea level. During the last 2 000 a, the amplitude of temperature changes at Guliya (over 6 000 m a.s.l.) in the Q-T Plateau reached 7℃, in comparison with 2℃ in eastern China at low altitude. In the present age, apparent differences of climatic warming have been observed in the Q-T Plateau, indicating that the warming in high-elevation regions is much higher than that in low-elevation regions. The temperature in over 3 500 m regions of the Q-T Plateau have been increasing at a rate of 0.25×10^{1}/a in recent 30 years, but almost no change has taken place in the regions below 500 m. Thus, we concluded that high-altitude regions are more sensitive to climatic changes than the low-altitude regions.

Keywords: Qinghai-Tibetan Plateau, high elevation region, abrupt climatic change, amplitude of climatic change, climatic sensitivity.

The present article focuses on the abrupt climatic changes in and around the Qinghai-Tibetan (Q-T) Plateau. Because of the high elevation of the Q-T Plateau, the most frequently asked questions related to the abrupt climatic changes in the Q-T Plateau might be: What is the basic feature of climatic changes in the Q-T Plateau? What is the difference of the climatic change between the Q-T Plateau and the lower altitude regions?

An important topic related to the above questions is the abrupt climatic change. Abrupt changes in the Earth's climate system have attracted much interest recently as these events are rapid, nonlinear, unpredictable at present and have a great impact on the human activities. It is, therefore, important to study the feature and mechanism and to make prediction in the future.

The study of abrupt climatic change is related to very broad areas, for instance, the study of abrupt climatic change can be related to the amplitude, the frequency and the phase of climatic change. Here we discuss mainly on the amplitude of climatic change. Climatic change is mainly composed of two factors: temperature and precipitation. The present article only discusses the temperature factor.

The information about large amplitude of rapid climatic change was recorded in two ice cores (GRIP and GISP2) in Greenland [1], characterized by many sharp climatic oscillations in the past 100 ka. Most of the abrupt climatic variations with large amplitude had occurred during transitional stages from warm to cold or from cold to warm, in comparison with the relatively small amplitude during the glacial maximum and last interglacial.

Younger Dryas recorded in Greenland ice cores is considered the largest amplitude of climatic variation event in which temperature decreased to 15℃±3℃[2], accompanied by precipitation reduction at the same time as reported by Alley[3], snow accumulation had reduced by 50% and the measured wind-blown dust had been doubled[4, 5].

Recent findings from ice cores suggested that the large amplitude of climatic change had happened not only in Atlantic region but also in the Q-T Plateau[6, 7]. As studied by Yao et al.[8], the amplitude of climatic change in the Q-T Plateau was much larger than that in Greenland.

The above findings remind glaciologists and climatologists of thinking about the following questions: Are the amplitudes of the past and the present climatic changes larger at the high altitude (such as the Q-T Plateau) than at the lower altitude?

This article will clarify the characteristics of variation amplitude of the climate in the Q-T region and compare these features with those in other low-altitude regions.

1 Data and method

(i) Data from the Guliya ice core. Three ice cores were drilled from the largest ice cap (Guliya Ice Cap) in the Q-T Plateau to reconstruct the past climatic history, with the lengths of 308.7, 93.2 and 34.5 m respectively. The 308.7-m core reached the bedrock.

According to the study[6], the Guliya Ice Cap is the largest polar type ice cap in central Asia with an area of 376 km^2. Temperatures at the depths of 10, 220 m and the bottom are −15.6, −5.9 and −2.1 ℃, respectively, indicating that the ice core is qualified to reconstruct the past climatic changes.

After the recovery of the three ice cores, they were equally shared between the Lanzhou Institute of Glaciology and Geocryology and the Ohio State University. The data present here were measured at the Lanzhou Institute of Glaciology and Geocryology.

Detailed studies of climatic changes recorded in Guliya ice cores in the past 2 000 years have been carried out by Shi et al.[9] and Yao et al.[10]. If $\delta^{18}O$ is used as a proxy of temperature (T), their relation is[11]

$$\delta^{18}O(‰) = 0.67T - 13.59, \quad R^2 = 0.69.$$

The equation presents a gradient of 0.67%×10 ^{1}/℃.

(ii) Meteorological data. Data of mean monthly air temperature from 165 meteorological stations in the Q-T Plateau and adjacent regions have been collected for comparing the features of climatic change at different elevations. The mean temperature anomalies of each spring (March—May), summer (June—August), autumn (September—November) and winter (December—next February) of the past 30 years have been calculated based on monthly temperature anomalies, to get the linear increasing rate and temperature differences in the 1980s and 1960s. Then the 165 stations have been classified into five elevation zones for statistics of mean temperature increasing rates and mean temperature differences of each elevation zone.

(iii) Data from other regions outside the Q-T Plateau. To compare the amplitude of climatic change in the Q-T Plateau with that in other regions of the world, the paleo-temperature data from different media have been collected. They are mainly from CLIMAP[12, 13], Broecker[14], Thunell et al.[15], Bard et al.[16] for the sea surface temperature reconstruction, from Stute[17], Newsome et al.[18], Gannen and Absy[19], Hammen and Gonzalez[20], Helsmens and Fuhry[21], Rodbel[22] and Thompson et al.[23] for the continental temperature reconstruction by pollen, snowline fluctuations, glacial deposits, noble gases and ice cores.

2 Amplitude of climatic changes in different periods in the Q-T Plateau

(i) Amplitude of clamatic changes recorded in Guliya ice core of the Q-T Plateau. According to the study of the Guliya ice core (fig. 1), the mean $\delta^{18}O$ values of the Guliya ice core in the past 2 000 years and the 20th century was −15.25‰ and −13.89‰ respectively, demonstrating that oxygen isotopes have increased by 1.36‰ since 2 000 aBP, equivalent to a temperature increase of 2℃. However, isotopic profiles show that many abrupt climatic changes occurred during the period. There were 33 climatic oscillations identified from the 5th to 20th century, with $\delta^{18}O$ variation amplitude over 2‰, equivalent to over 3℃ in temperature. 12 abrupt changes, with temperature decrease larger than 3.5℃, are distinguished in fig. 1. Some large amplitudes of temperature variations reached over 7℃. The Little Ice Age was the largest abrupt climatic variation event from the past 2 000 a, with consistent variations of temperature and precipitation (fig. 1).

Zhang et al.[24] suggested that there were two cold periods between 485 (AD) and 580 (AD), which correspond to the two great temperature depressions in 480 (AD) (4‰ $\delta^{18}O$ reduction) and 550 (AD) (4.4‰ $\delta^{18}O$ reduction). Three cold stages during the Little Ice Age as signed in the Guliya ice core agreed approximately to those in eastern China despite their different locations. However, there existed great difference of temperature variation amplitude between Guliya and eastern China. The temperature at Guliya varied over 7℃ but there were only 2℃[24] decreased in eastern China during the

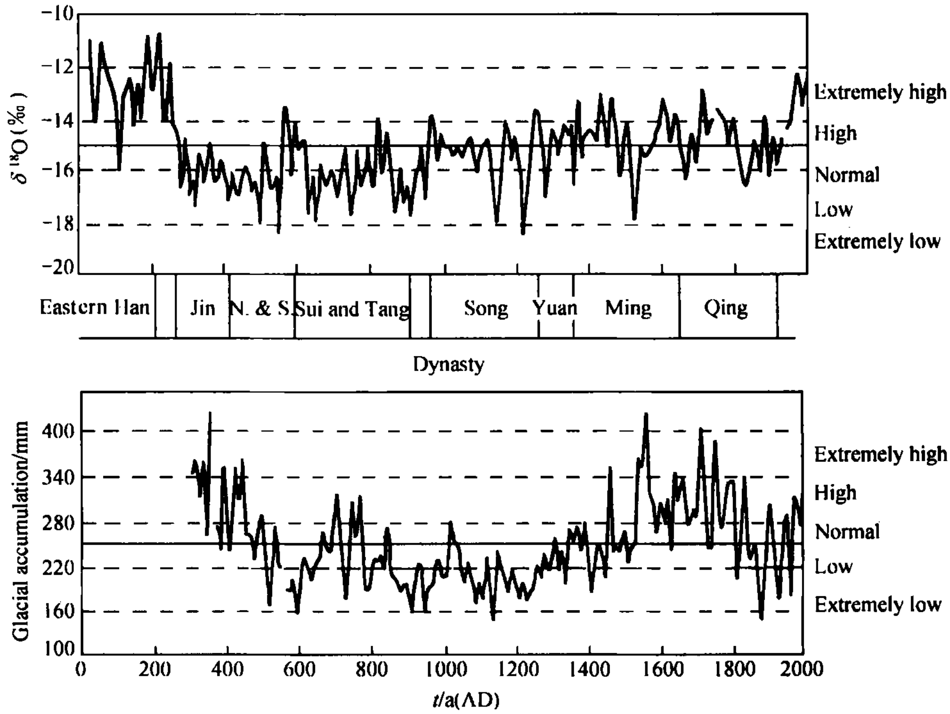

Fig. 1. Climatic changes with large amplitude in the Guliya ice core during the past 2 000 a. N. & S. stand for the Northern and Southern Dynasties.

cold stage in about 500 (AD) and only 1.5℃ in about 800 (AD). Comparing the ice core record in Tibet with the historical record in eastern China shows that climatic changes in the Q-T Plateau are characterized apparently by large amplitudes.

The ice core records from the Guliya ice core are considered to be the most detailed in reflecting the climatic variations in the Q-T Plateau during the past 100 ka. In order to reveal the differences of climatic changes between the Q-T Plateau and other low-altitude regions, the climatic signals in the Guliya ice core have been compared with those in a 100 ka GRIP ice core in Greenland.

Fourteen warm events indicated by moving averagely 11 points from both Guliya and Greenland GRIP ice cores show their corresponding relations (fig. 2). However, there are three points concerning the difference between them: i) The oxygen isotopes in the Guliya ice core generally varied earlier than those in Greenland GRIP. Among the total 14 warm events, 13 at Guliya occurred earlier than those of Greenland GRIP. ii) The amplitude of oxygen isotopic variations in Guliya was larger than that in Greenland GRIP. Variation of $\delta^{18}O$ between glacial and interglacial stages in Guliya in the past 100 ka was about −2℃ higher than that in Greenland GRIP, equal to 3℃ in temperature. iii) During the transition periods from the glacial to interglacial stages, the cooling rate in Guliya was much faster than that in Greenland GRIP, reflecting that this transition process completed in quite a short time in Guliya. That is to say, the transition from point 12 to point 11 could finish within 20 a in Guliya but it needed 50 a in Greenland (fig. 2). In summary, the climatic cycles in Guliya were characterized by large amplitude of variations and fast cooling .

Although the temporal comparison between Guliya and Greenland GRIP have shown that the amplitude of climatic oscillations in Guliya was larger than that in Greenland, we need more work to confirm that the climatic variations are characterized by relatively large amplitude in high-elevation regions in comparison with that in low-elevation regions. In the light of δD records in Vostok ice core, the temperature difference between the Last Glacial Maximum (LGM) and the present is 8℃. Thompson[7] suggested that the change of $\delta^{18}O$ in GISP2 ice core between the LGM and the present is

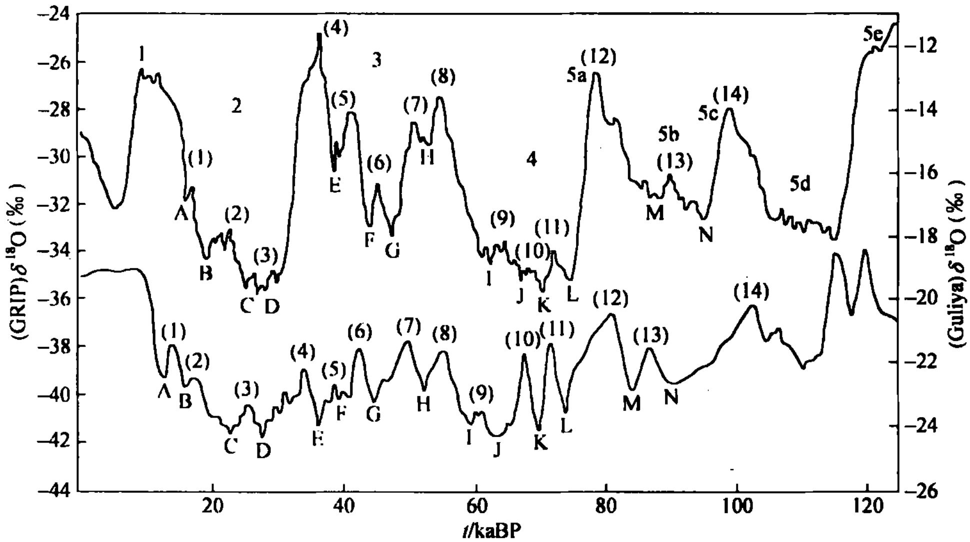

Fig. 2. A comparison of major climatic changes in the Guliya ice core with those in GRIP ice core of Greenland during the last 100 ka. The capitalized letters refer to the apparent cold stages, and the numbers without brackets refer to the apparent warm stages while numbers in brackets indicate minor-climatic events. 5a, 5b, 5c, 5d and 5e were the five stages during the last interglacial.

5.1‰, corresponding to a temperature difference of 7.4℃ according to Dangaard's gradient of 0.69‰ per ℃. The temperature difference in Guliya between the LGM and the present could reach 9.5℃, on the basis of the δ^{18}O/temperature gradient of 0.69‰ per ℃ in the Q-T Plateau. The above calculated values of temperature differences indicated by ice core records from Guliya, Greenland, Vostok and Huascaran are listed in table 1. It is evident that the amplitude of temperature variations between LGM and the present in two high-elevation ice cores (in Guliya and Huascaran) was higher than that in two low-elevation ice cores (in Greenland and Antarctica).

Table 1 Comparison of temperature difference between the Last Glacial Maximum and the present in 4 ice cores in different elevations of the world

Ice core	Temperature difference/℃	Elevation/m (a.s.l.)
Guliya in China	8.1	6 200
Huascaran in Peru	9.5	6 300
Vostok in Antarctica	8.0	3 600
GISP2 in Greenland	7.4	3 200

According to the modeling results [25], the annual scope of global temperature varied at different latitudes during the last glacial maximum, generally increasing with latitude. If $\Delta T\varphi$ stands for the amplitude of latitudinal temperature decrease between the LGM and the present at latitude φ, the following equation is suitable for describing the latitudinal changes of temperature decrease:

$$\Delta T\varphi = 2.173 + 3.988\sin\varphi - 28.324\sin^2\varphi - 31.815\sin^3\varphi + 100.306\sin^4\varphi + 101.701\sin^5\varphi + 63.522\sin^6\varphi - 74.869\sin^7\varphi, \quad (R^2=0.95),$$

where R is a relationship coefficient.

This equation clearly indicates that the amplitude of climatic change is largely increased with the increase of latitude. It is, therefore, necessary to calibrate the values in table 1 to eliminate the latitude effect. The calibrated values are listed in table 2. It is evident that the altitude impact on the amplitude of climatic change is tremendous. The two sites with high altitude (the Q-T Plateau and Andes) are characterized by large amplitudes which are much higher than the two relatively low sites (Arctic and Antarctica).

Table 2 Calibrated values of the amplitude of climatic change in different latitudinal regions

Region	Amplitude before calibration /℃	Amplitude after calibration /℃	Altitude /m (a.s.l.)
Arctic	7.4	0.8	3 200
Q-T	8.1	6.4	6 200
Andes	9.5	8.8	6 300
Antarctica	8.0	0.0	3 600

Recently, numerous results of paleoclimatic studies obtained from the tropical and subtropical regions have helped us to compare the features of climatic changes in the Q-T Plateau with other regions. According to the reconstruction of global sea surface temperature during the Last Glaciation by CLIMAP[12, 13], the study of the temperature difference between the Last Glaciation and the Holocene by Broecker[14], the sea surface temperature reconstruction in the West Pacific by Thunell et al.[15] and in the Indian Ocean, the temperature on the most global areas at sea level between glaciation and interglaciation varied in the scope of 1.5—2℃. All the data from different locations and elevations of the world implied that the amplitude of the continental temperature variations was higher than that of sea surface. The amplitudes of temperature changes between glacial and interglacial cycles indicated by the measurements of noble gases dissolved in groundwater in Brazil (400 m a.s.l.) and the pollen analysis from a sediment rock core near the central highland of an Indonesian island were 5.2℃ and 5.4℃[17,18], the maximum can be as high as 7℃[26]. Temperature differences between glacial and interglacial stages, as reflected by pollen analysis from the equatorial regions at 2 560 and 3 250 m in South America, ranged from 5—8℃[19, 20] to 7—8℃[21], respectively. Based on snowline study, Rodbell[22] found that the amplitude between glacial and interglacial stages in a mountain in South America was more than 6℃. Thompson et al. [23] recently estimated that temperature variation between glacial and interglacial cycles, as recorded in an ice core from Andes (6 048 m), reached over 9℃.

These findings demonstrate that the temperature amplitude in the tropics changed with elevation. The amplitude of temperature variations in high-altitude regions was higher than that in low-altitude regions. Fig. 3 shows the altitudinal changes of temperature amplitudes between glacial and interglacial stages from different media in the tropics, indicating that the temperature variations were about 4℃ near sea level and 12℃ at 6 500 m elevation. The amplitude of temperature changes over 6 000 m has

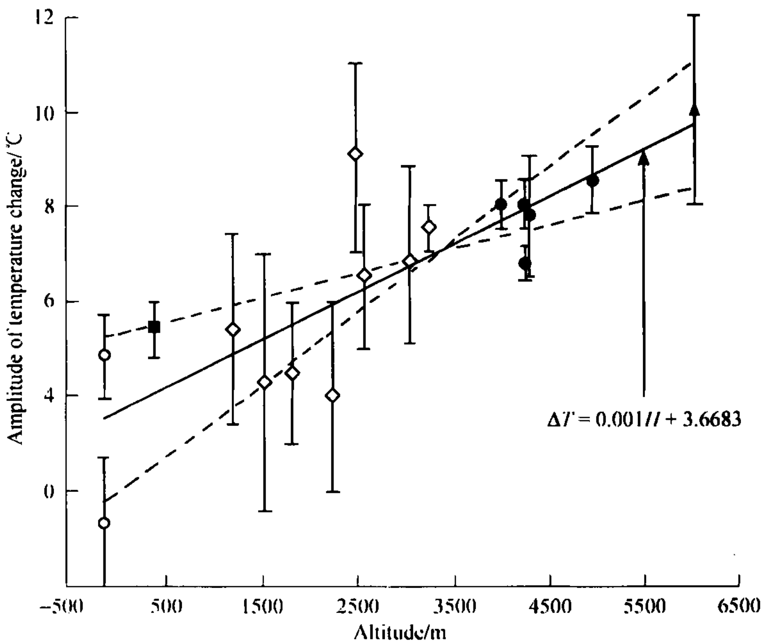

Fig. 3. Altitudinal variations of temperature differences between glacial and interglacial stages from different media in the tropics. ○, Oceanic data; ■, noble gases; ◊, pollen; ●, snowline data; ▲, ice core.

been described by records in Guliya and Hauscaran ice cores. A lot of recent evidence show that the possible amplitude of temperature variations above sea level and lowland was about 4℃. According to Stuijts et al.[26], Colinvaux et al.[27, 28] and Richard et al.[29], the temperature change between the Last Glaciation and the Holocene is 5—6℃. Bush et al.[30] reported that the temperature depression in a tropical lowland lake from warm to cold periods was around 5℃, close to the result of coral research in southern coast of Barbados by Thomas et al.[31]. These pieces of evidence suggested that the temperature differences on sea level from glacial to interglacial stages ranged from 2℃ to 4℃ in comparison with that over 4℃ on the surface of lowland neighboring oceans, as a result of different heat capacities between continent and ocean. These findings are coherent with the results in fig. 3.

(ii) Amplitude of recent climatic change and its relation to altitude in the Qinghai-Tibetan Plateau. The temperature increase rate and temperature difference of the Qinghai-Tibetan Plateau and surrounding regions are listed in table 3. Our study from the instrumental record of temperature variations in the Q-T Plateau and nearby regions reveals a strong elevation-depending feature. The seasonal comparisons of the same elevation zone indicated that the temperature increase rates were rising from spring and summer to autumn and winter, with the highest increasing rate in winter[32].

Table 3 Altitude change of the mean temperature increasing rates (℃ × 10 $^{-1}$/a) in the Q-T Plateau and adjacent regions between 1961 and 1990, and the mean temperature differences (℃) in the 1980s and 1960s

Altitude/m	Station No.	Spring	Summer	Autumn	Winter	Year
<500	34	-0.18	-0.07	0.08	0.16	0.00
		-0.32	-0.11	0.08	0.24	-0.03
500 — 1 500	37	-0.11	-0.02	0.16	0.42	0.11
		-0.16	0.04	0.30	0.70	0.22
1 500 — 2 500	26	-0.17	0.03	0.15	0.46	0.12
		-0.30	0.14	0.28	0.73	0.21
2 500 — 3 500	38	-0.01	0.02	0.19	0.63	0.19
		-0.20	0.16	0.44	0.10	0.37
>3 500	30	0.12	0.14	0.28	0.46	0.25
		0.22	0.41	0.62	0.83	0.52

The data in table 3 display the features of climatic cooling in springs and warming in autumns and winters in the recent 30 years, with the highest increasing amplitude in winter. However, the temperature increase rates at 30 stations over 3 500 m a.s.l. in each season were positive, inferring a tendency of temperature increase. Although the annual temperature increase rate at the stations below 500 m is zero, it is 0.12 between 1 500—2 500 m, and reached 0.25℃ × 10 $^{-1}$ /a above 3 500 m. As can be seen in table 3, it is apparent that the annual increasing rate of temperature rises with altitude. Fig. 4 gives a clear picture of these variations.

The 30-year data can be divided into two groups of 1961—1975 and 1976—1990. According to monthly total of the positive and negative temperature anomalies of the stations in each divided elevation zone as shown in table 4, their ratios were calculated (table 3). The statistical results show that the ratios in other elevation zones between 1961 and 1975 were below 1, except that of > 500 m zone (ratio was 1), reflecting that it was a colder stage. Conversely, the ratios in other elevation zones between 1976 and 1990 were over 1, except that of > 500 m zone (ratio was 0.99), indicating that it was a warmer stage. The interesting phenomenon is that the temperature differences in the elevations of <500 m during this two stages, especially in that over 3 500 m, were much larger than that below 500 m.

Therefore we can conclude that there exists a close relation between climatic warming and elevation during the recent 30 years, particularly in winters.

Table 4 Ratios of monthly total of the positive and negative temperature anomalies, and total stations in each elevation zone

Altitude/m	<500	500—1 500	1 500—2 500	2 500—3 500	>3 500
1961—1975	1.00	0.95	0.98	0.92	0.88
1976—1990	0.99	1.09	1.04	1.05	1.18

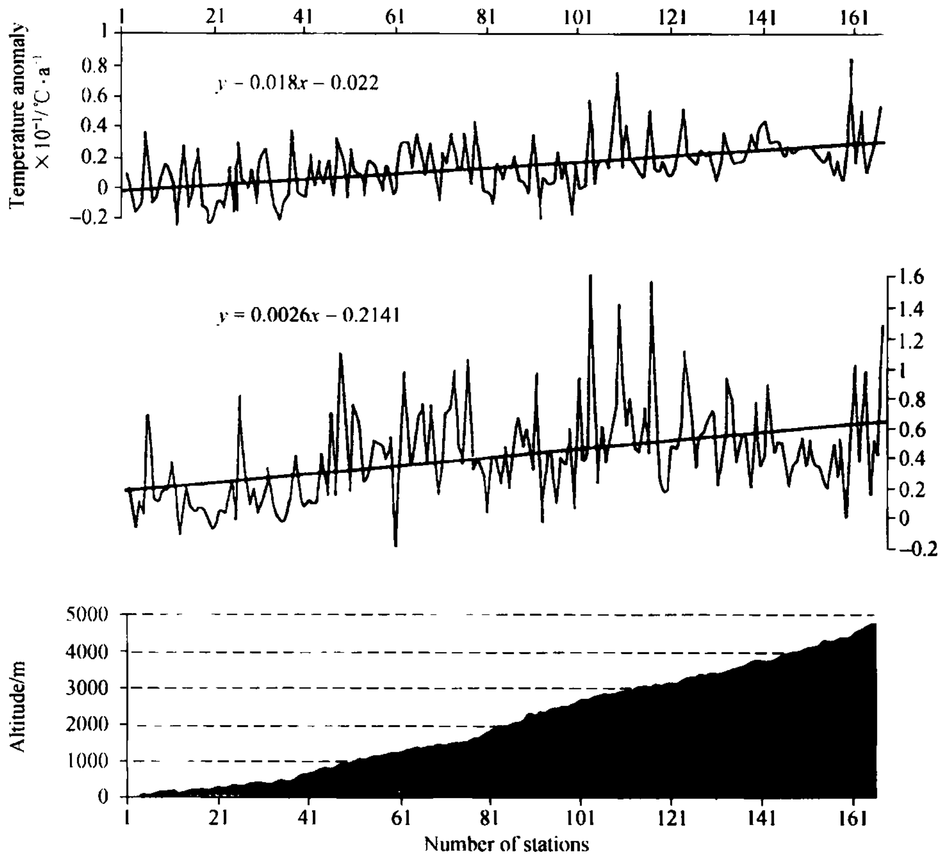

Fig. 4. Relation between recent climatic change and elevation in the Q-T Plateau and nearby regions.

3 A possible mechanism of large amplitude of climatic oscillations in the Q-T Plateau

It is clear from the above discussion that the amplitude of climatic change at high altitude is larger than that at low altitude. What is the mechanism resulting in the feature? There is no absolute and unique answer at present. Further studies should be concentrated on looking for its mechanisms and causes by close cooperation of climatologists and computer modelists, in order to give an accurate and quantitative answer. On the basis of present knowledge, the climatic phenomena may be interpreted from two aspects.

A possible mechanism proposed here is the variations of snow coverage on the earth's surface. Large amplitude of climatic changes in the Q-T Plateau might mainly result from the development or reduction of snow and ice covering on land surface. Because the increase of the area and thickness of snow cover with altitude strengthened their feedback effects, the process of climatic cooling in high-elevation regions during glaciations would be faster than that in low-elevation regions. These effects would result in relatively large amplitude of climatic variation in high-altitude regions in comparison with that in low-altitude regions and lead to the abrupt climatic changes. This probably was a basic reason causing the rapid climatic processes from warm to cold as recorded in the Guliya ice core in the Q-T Plateau.

Wang et al.[33] thought that the water vapor change in atmosphere would cause the change of temperature lapse rate, which will result in the change of amplitude of climatic change. This might also be important in the study of climatic change amplitude at high altitude.

Acknowledgements This work was supported by the National Basic Research Program (Grant No. 1998040802) and Key Programs of the Chinese Academy of Sciences (Grant Nos. KZ951-A1-204-02 and KZ951-A1-402-03).

References

1. Cuffey, K. M., Clow, R. B., Alley, M. et al., Larger Arctic-temperature change at Wisconsin-Holocene transition, Science, 1995, 270: 455.
2. Severinghaus, J. P., Sover, T., Brook, E. J. et al., Timing of abrupt climate change at the end of Younger Dryas interval from thermally fractionated gases in polar ice, Nature, 1998, 391: 141.
3. Alley, R. B., Meese, D., Shuman, C. A. et al., Abrupt increase in Greenland snow accumulation at the end of the Younger Dryas event, Nature, 1993, 362: 527.
4. Mayewski, P. A., Meeker, L. D., Whitlow, S. I. et al., The atmosphere during Younger Dryas, Science, 1993, 261: 195.
5. Zielinski, G. A., Mayewski, P. A., Meeker, L. D. et al., A 11000 year record of explosive volcanism from the GISP2 (Greenland) ice core, Quat. Res., 1996, 45: 109.
6. Yao Tandong, Thompson, L. G., Shi Yafeng et al., The climatic variations since the Last Interglaciation recorded in the Guliya ice core, Science in China, Ser. D, 1997, 40: 662
7. Thompson, L. G., Yao T. D., Davis, M. E. et al., Tropical climatic instability: the last glacial cycle from a Qinghai-Tibetan ice core, Science, 1997, 276: 1981.
8. Yao Tandong, Abrupt climatic variations on the Qinghai-Tibetan Plateau during the Last Ice Age — a comparative study of the Guliya ice core with the GRIP ice core, Science in China, Ser. D, 1999, 42: 358.
9. Shi Yafeng, Yao Tandong, Kang Xincheng et al., A comparison between the climatic variation in Guliya ice core and that in eastern China, Science in China, Ser. D, 1999, 42(supp.): 79.
10. Yao Tandong, Yang Zhihong, Kang Xingchen et al., Variations of cryosphere and atmosphere on the Tibetan Plateau, Cryosphere, 1997, 2: 1.
11. Yao Tandong, Thompson, L. G., Thompson, E. M. et al., Climatological significance of $\delta^{18}O$ in North Tibetan ice cores, J.G.R., 1997, 101(23): 29531.
12. CLIMAP Project Members, The surface of the ice age earth, Science, 1976, 191: 1131.
13. CLIMAP Project Members, Seasonal reconstructions of the earth's surface at the Last Glacial Maximum, Geological Society of American Map and Chart Series Mc-36, edited and published by Geological Society of America, 1981.
14. Broecker, W. S., Oxygen isotope constraints on surface ocean temperature, Quaternary Research, 1986, 26: 121.
15. Thunell, R., Anderson, D., Gellar, D., Sea-surface temperature estimates for the tropical western Pacific during the Last Glaciation and their implications for the Pacific Warm Pool, Quaternary Research,1994, 43: 255.
16. Bard, E., Rostek, F., Sonzogni, C., Interhemispheric synchrony of the last deglaciation inferred from alkenone paleothemometry, Nature, 1997, 385: 707.
17. Stute, M., Forster, M., Frischkon, H., Cooling of the tropical Brazil during the Last Glacial Maximum, Science, 1995, 269 (5222): 379.
18. Newsome, J., Flenley, J. R., Late Quaternary vegetational history of the central highland of Sumatra (II)——Paleopalynology and vegetational history, Journal of Biogeography, 15: 555.
19. Van der Gannen, V. T., Absy, M. L., Amazonia during the Last Glacial, Paleogeography, Paleoclimatology, Paleoecology, 1994, 104: 247.
20. Van der Hammen, V. T., Gonzalez, A. E., Upper Pleistocene and Holocene climate and vegetation of the Sabana de Bogota, Colombia, South America, Leide Geologische Mededelingen, 1960, 25: 126.
21. Helsmens, K. F., Fuhry, P., Middle and Late Quaternary vegetational and climatic history of the Paramo de Agua Blanca (Eastern Cordillera, Colombia), Paleogeography, Paleoclimatology, Paleoecology, 1986, 56: 291.
22. Rodbell, D. T., Late Pleistocene equilibrium-line reconstructions in the northern Peruvian Andes, Boreas, 1996, 21: 43.
23. Thompson, L. G., Mosley-Thompson, M. D., Late glacial stage and Holocene tropic ice core records from Huascaran, Peru, Science, 1995, 269: 46.
24. Zhang Peiyuan (ed.), Historical Climate Changes (in Chinese), Ji'nan: Shandong Science and Technology Press, 1996, 195—440.
25. Liu, X., An, Z., Wu, X. et al., East Asian Paleoclimates of the Last Glacial Maximum in an atmospheric general circulation model and from geological records, Proc. 30th Int. Geol. Congr., 1997, 21: 156.
26. Stuijts, I., Newsome, J. C., Flenley, J. R., Evidence for the Late Quaternary vegetational change in the Sumatran and Javan highlands, Review of Paleobotany and Palynology, 55: 207.
27. Colinvaux, P. A. Oliveira, P. E., Moreno, J. E. et al., A long pollen record from lowland Amazon: forest and cooling in glacial times, Science, 1996, 274: 85.
28. Colinvaux, P. A., Liu, K. B., Paulo de Oliveira et al., Temperature depression in the lowland tropics in glacial times, Climatic Change, 1996, 32(1): 19.
29. Richard, A. K., Ice-Age rain forest found moist, coller, Science, 1996, 274: 35.
30. Bush, M. B., Piperno, D. R., Colinkaux, P. A. et al., A 14300-year paleoecological profile of a lowland tropical lake in Parama, Ecol. Monag, 1992, 64: 251.
31. Guiderson, T. P., Fairbanks, R. G., Rubenstone, L., Tropical temperature variations since 20 000 years ago: modulating inter-hemispheric climatic change, Science, 1993, 263: 663.
32. Liu, X., Hou, P., The relation between climatic warming and elevation in the Qinghai-Tibetan Plateau and adjacent areas in recent 30 years, Plateau Meteorology (in Chinese), 1998, 17: 245.
33. Wang Ninglian, Yao Tandong, Shi Yafeng et al., Magnitude of temperature depression in equatorial regions during the Last Glacial Maximum, Science in China, Ser. D, 1999, 42(supp.): 80.

(Received November 10, 1999)