Annals of Glaciology 14 1990

GLACIER RECESSION AND LAKE SHRINKAGE INDICATING A CLIMATIC WARMING AND DRYING TREND IN CENTRAL ASIA

by

Shi Yafeng and Ren Jiawen

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

ABSTRACT

Mass balance observations on Urumqi River No. 1 Glacier and Tuyuksu Glacier in Tianshan show a large deficit during the 1980s as compared to the decades before. The Qinghai Lake in northeastern Qinghai-Xizang (Tibet) Plateau and the Issyk-kul Lake in Soviet Tianshan have been continuously shrinking during the past few centuries. Since the maximum of the Little Ice Age which occurred mainly in the 18th century, glaciers have decreased in area by about 44% in the Urumqi valley. These data and other evidence from glaciers, lakes, etc. clearly indicate that the climatic warming and drying tendency grows stronger in this century and will possibly persist to the early decades of the next century. The growing greenhouse effect due to the increase of CO_2 and other related gases will enhance this tendency in the near future. However, should the high temperature period of the early and middle Holocene re-appear, the climate would become humid.

INTRODUCTION

Alpine glaciers and inland lakes are indicators of climatic change because their expansion or contraction reflects changes of water balance and heat conditions in mountainous regions. Water resources in Central Asia stem mainly from mountains and plateaux such as Tianshan, Altay and Pamir (Fig. 1). Run-off from the mountains determine the water resources and controls the economic development in the regions. Therefore, judging the climatic conditions from data of glacier and lake variations helps in predicting future climate and water resources.

GLACIER VARIATIONS

From the data of various glacier variations from the 1950s to 1980s as listed in Table I, one can see that threequarters of the glaciers in the mountains of Central Asia have been in recession. If only glaciers less than 10 km long are counted, the proportion is much higher. Glacial response to climatic change involves a time-lag, dependent on the amplitude of climatic changes and glacier extent. Small glaciers are generally more sensitive than larger ones.

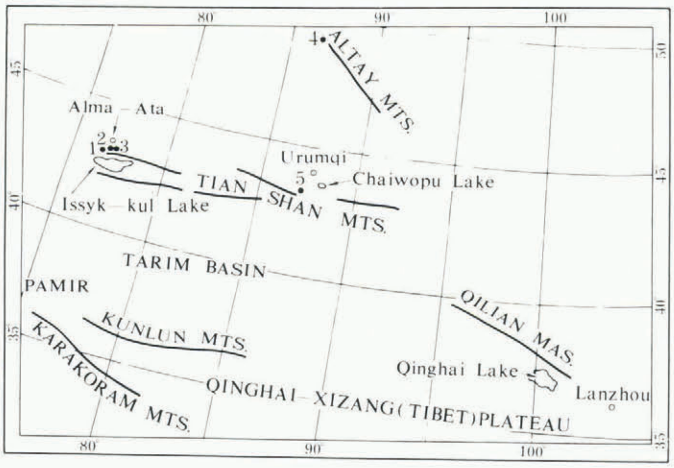

Fig. 1. Locations of mountains, glaciers and lakes in Central Asia mentioned in this paper. Glaciers: 1. Golubina, 2. Tuyuksu, 3. Molodezhniy, 4. Maliy Aktru, 5. Urumqi R. No. 1.

Urumqi River No. 1 Glacier, a small cirque-valley glacier with double tributaries, has been retreating and thinning since the start of observation in 1959. The mass balance may imply the climatic state of the same period. During the thirty years 1959–88, negative mass balance of the glacier occurred in 19 years, and since 1973 only two years showed a small surplus. As shown in Figure 2b, the value of negative balance in the 1980s is much higher than that in the 1960s and 1970s. The data of mass balance on glaciers in the Soviet Tianshan and Altay (Table II) also indicate deficiency after 1973.

TABLE I. FLUCTUATIONS OF GLACIERS IN CENTRAL ASIA FROM THE 1950s TO 1980s
(Source: Soviet data from *Materialy Glyatsiologicheskikh Issledovaniy*, Vyp. 62 [*Data of Glaciological Studies*, (Publication No. 62)], 1988; Chinese data from Ren (1988))

Mountains	Country	Glaciers counted	Advancing	Retreating	Stable
Altay	USSR	26	0	26	0
Altay	China	5	1	4	0
Tianshan	USSR	58	8	50	0
Tianshan	China	43	5	29	9
Pamir	USSR	40	10	25	5
Pamir	China	11	2	7	2
Qilian Shan	China	44	8	25	11
Total		227	34(15%)	166(73%)	27(12%)

TABLE II. SOME RECENT MASS BALANCE RESULTS OF GLACIERS IN CENTRAL ASIA
(Source: Urumqi River No. 1 Glacier from Tianshan Glaciological Station, LIGG, China; others from *Materialy Glyatsiologicheskikh Issledovaniy*, Vyp. 62 [*Data of Glaciological Studies*, (Publication No. 62)], 1988)

Mountains	Glacier	Area (km^2)	Elevation (m)	Time interval	Balance total (mm)	Mean (mm/a^{-1})	Time interval	Balance total (mm)	Mean (mm/a^{-1})
Tianshan	Urumqi R. No. 1	1.84	3736–4484	1959–72	–392	–28	1973–88	–2705	–169
	Tuyuksu	3.02	3401–4219	1965–72	–500	–63	1973–87	–9450	–630
	Golubina	6.21	3250–4010	1969–72	+880	+220	1973–85	–2870	–220
	Molodezhniy	1.43	3450–4150	1965–72	–1890	–236	1973–82	–7430	–743
Altay	Maliy Aktru	3.80	2224–3714	1970–72	+280	+93	1973–85	–740	–62

Tuyuksu Glacier in the Soviet Tianshan (Fig. 1) has been under systematic investigation (Makarevich, 1985) and has the longest observation history in Central Asia. Figure 2a gives the variations with time of yearly summer temperature, annual precipitation, mass balance and snow line on the glacier since 1879 (values before 1956 are calculated). From Figure 2a one can see a general trend of climatic warming and drying since late last century, indicated by temperature rise, precipitation decrease, increasing mass deficit and ascending snow line. This is consistent with the global climatic warming during the last century. Since the late 1970s there has been some increase in precipitation on Tuyuksu Glacier, but its effect has been countered by temperature rise, so the mass deficit has remained on the increase and the snow line on the ascent. On Urumqi River No. 1 Glacier the temperature rise since the late 1970s is not large, but together with a continuous decrease in precipitation it has led to the same variations of mass balance and snow line as on Tuyuksu Glacier.

To cover the past several centuries, some judgments can be made with the aid of periglacial geomorphological features. There are three terminal moraines of the Little Ice Age at the front of glaciers in Central Asia mountains (Fig. 3). Tree ring data and lichenometric dating reveal that they formed in 1595–1650, 1765–1795 and 1820–1900 respectively in the Urumqi River valley (Zhang and others, 1984; Chen, 1988), and that the second moraine overlies the outer one at many sites. Tree ring data (Kang, 1984) and historical climatic documents show that the 18th century was a humid cold period, when glaciers advanced considerably. There were 143 glaciers with a total area of 67.6 km^2 in Daxigo, the main source of Urumqi River, at the maximum of Little Ice Age (Wang Zongtai, unpublished). By 1964 there were 124 glaciers left with a total area of 38 km^2, about 56% of that in the maximum of the Little Ice Age, and the snow line had risen 100–130 m. It is estimated from the correlation between the tree ring index and temperature that the summer temperature in the maximum of the Little

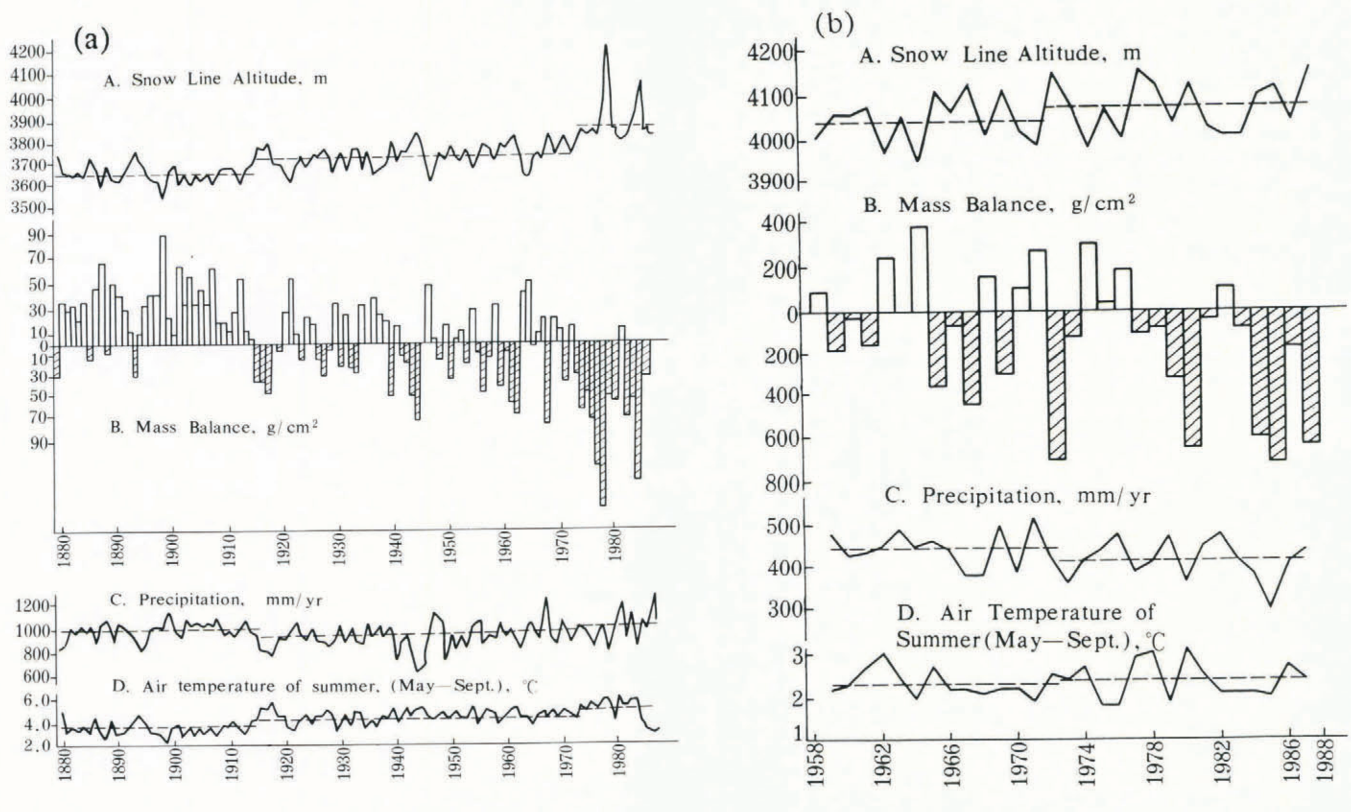

Fig. 2. Variations with time of snow line, mass balance, precipitation and summer (May–September) temperature at (b) Urumqi R. No. 1 Glacier and (a) Tuyuksu Glacier (after Makarevich, 1985).

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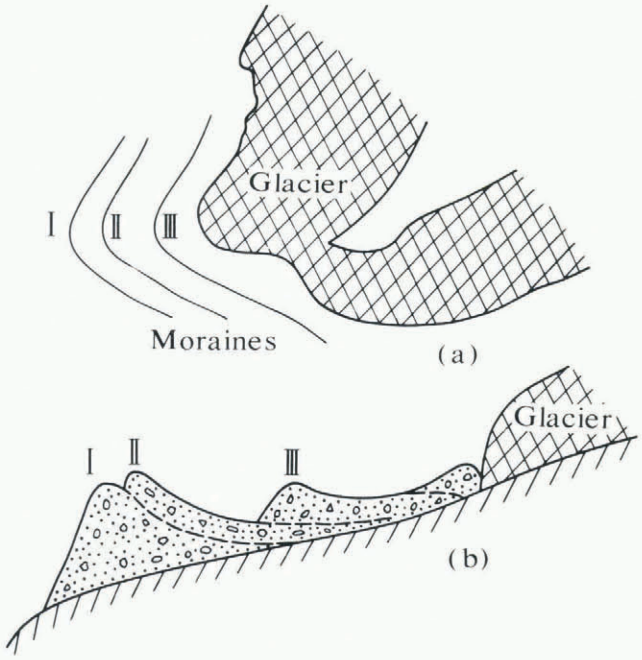

Fig. 3. Terminal moraines of Urumqi R. No. 1 Glacier since Little Ice Age, (a) plan view, (b) side view (after Wang, 1981).

Ice Age was 0.6 K lower than at present, the winter temperature 1.0 K lower and annual precipitation 50–100 mm more (Wang Zongtai, unpublished; Yao and Shi, 1988). These are illustrative of a climatic warming and drying during the past century since the Little Ice Age. To our surprise, about a 1.0 K rise of temperature and a slight decrease of precipitation result in more than a 40% contraction of glacier area in a basin where small glaciers are predominant.

LAKE VARIATIONS

Qinghai Lake is a big inland lake with an area of 4304 km^2 (1986), located in the northeastern Qinghai-Xizang (Tibet) Plateau and at the edge of the Asian monsoon region. Change of its level reflects sensitively climatic variations. Observations from 1956 to 1986 show that the level had fallen by 3.35 m. During this period nine warm and dry years contributed a drop of 2.36 m, about 70% of the total. Far back in 1908, a Russian expedition had noticed the lake had shrunk markedly (Kozloff, 1909). The lake level at that time is found to be 3205 m as inferred from the water depth. Table III illustrates the shrinkage of

TABLE III. SOME DATA ON QINGHAI LAKE SHRINKAGE

Year	Lake level (m a.s.l.)	Fall rate (cm a^{-1})	Lake area (km^2)	Mean rate of storage decrease (10^8 m^3 a^{-1})
1908	3205±		4980	
1957	3196.57	17.2	4568	8.21
1981	3193.92	11.0	4340	4.90
1986	3193.78	2.8	4304	1.21

TABLE IV. WATER BALANCE OF QINGHAI LAKE IN 1981 (10^8 m^3) (From Qinghai Hydrological Station, 1984)

Income		Evaporation	Balance
Precipitation	14.61 (337 mm)	41.21 (950 mm)	
Surface run-off	17.67		
Ground run-off	4.00		
Total	36.28	41.21	−4.93

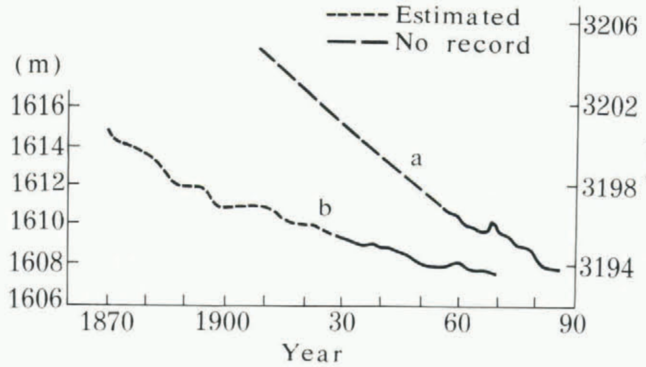

Fig. 4. The water budget and level fluctuations of Qinghai Lake. E(mm): annual evaporation of the lake surface, calculated by converting the Φ20 cm evaporation pan; P(mm): annual precipitation of the lake; Q(mm): run-off of catchment basin, shown by dividing the lake area; T(°C): mean annual temperature of Gangcha Station, north of Qinghai Lake; L: lake level; B: budget volume; A: lake area, measured from maps.

the lake since 1908, and water balance of the lake in 1981 is listed in Table IV. From Tables III and IV and Figure 4, it is seen that because of climatic warming and drying the evaporation has exceeded the sum of direct precipitation and inlet run-off, so that the lake level has been falling and its area decreasing (by 676 km^2 from 1908 to 1986). The rate of fall of lake level and the water deficit are larger in the first half of this century than in the second half. In the 1980s, less fall and deficit are expected since the shrinkage of the lake leads to decreasing area: an equilibrium state between loss and gain may appear in the near future.

Issyk-kul Lake in Soviet Tianshan has an area of 6236 km^2, 44% larger than Qinghai Lake. Its maximum depth is 668 m and the volume 1738 km^3, 22.6 times that of Qinghai Lake (76.9 km^3). The lake has been observed since 1910, when the level was 1610.8 m a.s.l.. Up to 1987 the level descended to 1606.5 m at a mean rate of 5.6 cm a^{-1} (Fig. 5). It is noticeable that the descent rate was 8 cm a^{-1} during 1910–1950 and reduced to 4.2 cm a^{-1} during 1950–1987 (Sevastynov and others, 1986). Most other lakes in arid Central Asia are behaving in a similar way.

From the facts mentioned above, inland lakes in Central Asia had a high water level during the period of the 16th to the 19th centuries under the humid cold climate of the Little Ice Age. Climatic warming and drying since then is the main cause of their shrinkage. However, when a lake has shrunk to a certain extent, resulting in a decrease of evaporation, human consumption of the lake water becomes more and more significant. For example, this consumption in the Qinghai Lake basin is estimated to be 0.8–1.0 × 10^8 m^3 a^{-1}, which is less than 20% of the total deficit rate during 1957–1981 but amounts to about threequarters of it during 1981–86.

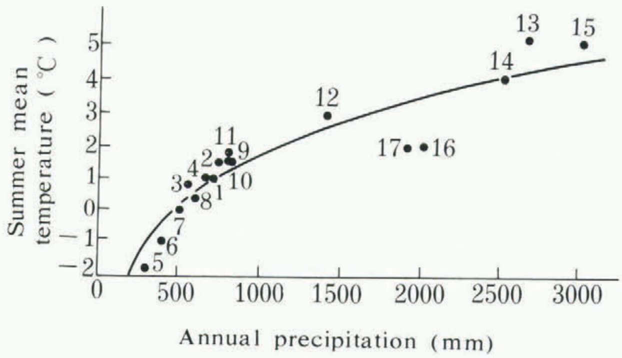

Fig. 5. Variations of lake level and its related factors of the Issyk-kul Lake in Soviet Tianshan. 1: Evaporation of the lake; 2: inflow (surface and ground); 3: lake level; 4: precipitation; 5: water for irrigation; 6: land evapotranspiration of the irrigated area; 7: tendency of fluctuation (Sevastynov and others, 1986, Fig. 27).

https://doi.org/10.3189/S0260305500008715 Published online by Cambridge University Press

HOLOCENE HUMID WARM CLIMATE INDICATED BY LAKE SEDIMENTS

The vegetation around Qinghai Lake is an alpine steppe, degenerating at present. Annual precipitation is about 350 mm and mean annual temperature −0.8 °C. According to archaeological findings and historical records, the lake extent in 540 A.D., when an ancient city by the name of Fuyi was built there, was larger than at present, but the lake level was a little lower than what was estimated early in this century (Fang and Huang, 1962). The lake sediments on the south rim, about 50 m above the present lake level, are dated to 4830 ± 130 years B.P. from C^{14} dating (correspondence from Wang Sumin, 1988). Other still higher sediments have also been found but their ages are unknown. A 5.22 m core was taken by drilling at the lake bed and was dated to after 12.3×10^3 years B.P. Below a depth of 6 m is a non-bedded eolian loess layer. From these and pollen analysis it is inferred that the lakeshore was in a dry cold steppe environment during the last glaciation (Zhang and others, 1988; Du and others, 1989). The snow line in the last glaciation indicated by the cirques on Qinghai Nanshan (south mountain) was between 4000 and 4200 m, about 600 m lower than at present. If temperature in the last glaciation was 6 K lower than at present, it is estimated from the relationship between summer temperature and annual precipitation at the snow line on glaciers in west China (Fig. 6) that in the last glaciation the mean summer temperature was 1 °C and the annual precipitation was about 300 mm at the snow line, decreasing to about 200 mm in the lakeshore area.

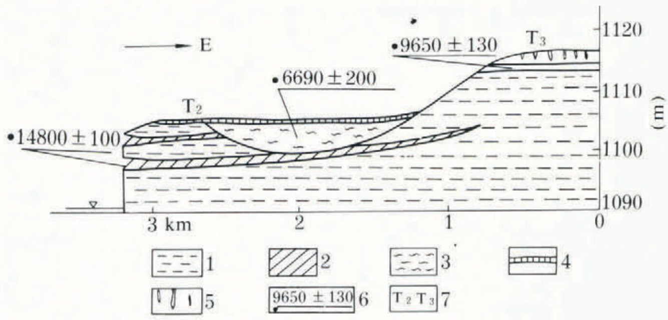

Fig. 6. Correlation between annual precipitation and summer (June–August) temperature at the equilibrium line on glaciers in west China (from Shi and Bai, 1988).

After the last glaciation, climate became warm and humid. In the middle Holocene (8000–3500 years B.P.), the vegetation was composed of a mixed broadleaf deciduous and conifer forest consisting of *Picea*, *Pinus*, *Abies*, *Betula* etc. from pollen analysis of the lake-bed drilling mentioned above. Recently, Qinghai Environmental and Hydrogeological Station found some *Picea purpurea* humus at 3400 m a.s.l. near Qinghai Lake and dated it to 6245 ± 180 years B.P. by C^{14} dating. This further confirms that there was a forest cover around the lake, implying annual precipitation of about 600 mm and mean annual temperature of 2–4 K higher than at present. The high water level during this period is further evidence of a humid climate.

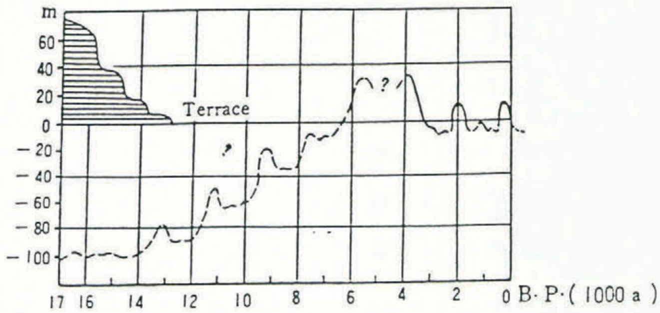

Fig. 7. Fluctuations of Issyk-kul Lake level according to historical and archaeological records (after Sevastynov and others, 1986, modified).

Since 3500 years B.P., i.e. late Holocene, the temperature decreased, while climate became drier. Up to 1500 years B.P. the lakeshore vegetation evolved into the present steppe environment from the forest prairie, and the lake level was falling.

According to the historical records and archaeological findings, Soviet scientists constructed the curves of the level fluctuations of the Issyk-kul as Figure 7 (Sevastynov and others, 1986, Fig. 32). About C^{14} dating 26 340 ± 540 years B.P., a higher lake level 30 m above the present appeared. During the end of late Pleistocene the cold and dry climate induced a much lower lake level about 100 m below the present. In the early Holocene, it was gradually rising and reached its maximum about 30–35 m higher than the present during 6000–4000 years B.P.. It undoubtedly represented a period of warm and humid climate. After this, in the 8–16th centuries the level fell unsteadily to 4–6 m lower than the present. During the 16–19th centuries, i.e. the Little Ice Age, the level again ascended to 13.5 m higher than the present when the precipitation amount was 10–20% larger and the temperature 1–2 K lower than that of the present (Pomorzev, 1988).

To sum up, during the early and middle Holocene warm period, when the climate was warmer and wetter than at present, a high lake level period occurred in Central Asia, which is comparable to the trend of water level change of Lake Chad and other lakes in North and East Africa and in west India (Kutzbach, 1980, 1981).

PROSPECTS FOR FUTURE CLIMATE, GLACIERS AND LAKES IN CENTRAL ASIA

Qinghai Lake and glaciers in the eastern Qilian Shan are located at the edge of Asian monsoon regions. Urumqi River No. 1 Glacier and Tuyuksu Glacier in Tianshan, glaciers in the Altay and Issyk-kul Lake represent the western part of inland Asia. In all these regions, the climate over the last 100 years has been warming and drying. The increase of mass deficit on glaciers since the 1970s may be implicated in the greenhouse effect of the increase of CO_2 and other trace gases. In the near future global climatic warming will possibly continue. If the temperature rises only slightly, atmospheric circulation remains steady and precipitation continues to decrease, Central Asia will become more arid, and water resources there will decrease.

If CO_2 and other gases enhancing the greenhouse effect increase so greatly that temperature rises by 1.5–4.5 K in the middle of the next century, i.e. the Holocene warm period reappears, the change of precipitation will be important. Judging by the circumstances in the Holocene warm period, Central Asia may become humid. The great increase of temperature will cause glaciers to melt by large amounts and small glaciers to disappear. The great increase of precipitation will make lake levels rise and river discharges increase. These are all advantageous to economic development in Central Asia. However, the effect of greenhouse gases may not necessarily be the same as the Milankovitch effect caused by the Earth's orbital change in the early Holocene. Therefore, variations of atmospheric circulation pattern, vapour transport and precipitation frequency, etc. are probably the key problems in studying and predicting the future climate in Central Asia.

ACKNOWLEDGEMENTS

This research is sponsored by the National Science Foundation of China and Chinese Academy of Sciences. The authors greatfully acknowledge the support of K.C. Wang Education Foundation (Hong Kong) for travelling expenses to join the Symposium on Ice and Climate of the International Glaciological Society and to present this paper.

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