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Temperature and precipitation fluctuations since 1600 A.D. provided by the Dunde Ice Cap, China

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ABSTRACT The temperature and precipitation fluctuations since 1600 A.D. have been studied from the Dunde Ice Core record. Oxygen isotope values reconstructed by historic data are consistent with the winter temperature record in Shanghai. Two cold periods were characterized by decreased glacial accumulation and two warm periods - by increased glacial accumulation. A comparison of the Dunde Ice Cap record (oxygen isotope and glacial accumulation), of the Shanghai winter temperature, and the tree ring record in the Qilian Mountain indicates that Qingzang Plateau is a trigger to the climatic change in China. An abrupt increase of oxygen isotope of the Dunde Ice Core in the twentieth century shows that CO_2 greenhouse effect is already recognizable in this area.

INTRODUCTION

To study the climatic and environmental history in Central Asia, an ice core program was carried out in the margin of the Qingzang Plateau, the Qilian Mountain, under the cooperation agreement between Lanzhou Institute of Glaciology and Geocryology, Academia Sinica and the Byrd Polar Research Center of the Ohio State University, USA.

In 1986 and 1987, ice cores were recovered from the Dunde Ice Cap in the Northwest China. Several papers were published (Thompson et al., 1989; Xie Zichu et al., 1989; Thompson et al., 1988) to report the primary results of the ice core analyses. The published results showed that the climatic and environmental information in the Dunde Ice Cap can be traced into the Last Glacial Maximum. The present paper is focused on the discussion about the temperature and precipitation fluctuation since 1600 A.D., since there is abundant data related to temperature and precipitation in the Qilian Mountains and in other regions of China during this period. Comparisons, therefore, can be made to recognize the identity and difference of climatic change in different regions of China and to check the representative of the Dunde Ice Cap record.

DATA ANALYSES

Two steps are very important in data analyses related to a climatic change study. The first is to obtain climatic information from an ice core. The second is the dating of the ice core. As to climatic information in case of ice core studies, temperature and precipitation are the most important factors. Temperature index is usually $\delta^{18}O$ or δD. The measurements of $\delta^{18}O$ and δD are well investigated. The application of $\delta^{18}O$ and δD to ice core study has also been successful. In the present study, $\delta^{18}O$ is used for denoting temperature index. Accumulation is used for precipitation index and calculated by the following model:

$$at = \lambda\ ws/w \qquad (1)$$

where λ is the thickness of annual ice layer, w - vertical velocity of glacial surface, ws - vertical velocity of ice layer in i-th year, for the value of w/ws we employed the model given by Raymond:

$$w/ws = 1-(1-h/H)(n+1)^{-1}[(n+2)-(1-h/H)^{h+1}] \qquad (2)$$

where H is glacial thickness, h - the depth from the ice layer to the bedrock of the glacier, n is taken here as number 3.

Dating of ice core is a very important aspect in the ice core study. Many methods were, therefore, applied to ice core dating. The dating of the Dunde Ice Core was made according to the variations of $\delta^{18}O$ and referred to the variations of microparticle concentration and conductivity at the same time. The basic principle to take $\delta^{18}O$ as an indicator of annual variation in ice core is that there is a big difference in $\delta^{18}O$ between winter snowfall and the summer one.

In glaciers of middle and low latitudes, a mud layer forms in the period between spring and summer. A microparticle concentration peak appears in this layer, conductivity is generally proportional to microparticle concentration and its peak corresponds to the peak of microparticle concentration. As discussed by Yao Tandong et al. (1989) in the Dunde Ice Core there is a good relationship in annual variations between microparticle concentration, $\delta^{18}O$, and conductivity. For example, in seasonal fluctuation a high microparticle concentration approximately corresponds to less negative $\delta^{18}O$ value and high conductivity, while a low microparticle concentration approximately corresponds to more negative $\delta^{18}O$ value and low conductivity. But this does not mean that less negative $\delta^{18}O$ absolutely corresponds to high microparticle concentration and high conductivity or more negative $\delta^{18}O$

absolutely corresponds to low microparticle concentration and low conductivity. This depends on the formation processes of $\delta^{18}O$, microparticle concentration, and conductivity. In the Dunde Ice Cap, less negative $\delta^{18}O$ value generally appears in the winter snow layer while high microparticle concentration appears in the snow layer between spring and summer. There is, therefore, a phase difference between $\delta^{18}O$ peak and microparticle concentration peak. The variation of conductivity is not only influenced by microparticle concentration, but also by salt and other chemical elements. Because of these reasons, the dating of the Dunde Ice Core since 1600 A.D. was mainly based on $\delta^{18}O$ and referred to microparticle concentration. When both $\delta^{18}O$ and microparticle concentration were not effective for dating, conductivity was used.

Since the 1950s, the global nuclear tests led to a dramatical increase of β-activity in the atmosphere. This activity was brought to glacier by snow and precipitation processes. Since the 1950s, the β-activity peak can clearly be found from ice core record. Because the dates of the global nuclear tests are already known, the date of the β-activity peak can also be traced. The β-activity peak is a good test indicator to check the ice core dating in the recent 20 to 30 years. This is also true of the check-up of the Dunde Ice Core.

RESULTS

Based on the dating by the above method, $\delta^{18}O$ and accumulation of the Dunde Ice Core were calculated for each year in the period from 1600 to 1986. Then, a 10 year average was estimated for both the $\delta^{18}O$ and accumulation as the index of temperature and precipitation respectively (Fig. 1). It can be seen from Fig. 1 that since 1600 A.D. there have been two obvious cold periods and two warm periods as reflected by $\delta^{18}O$ fluctuations. The first cold period started in 1600 and continued for 90 years. The second cold period was observed between 1770 and 1890. The coldest part of these two cold periods was between 1610 and 1680. The two warm periods were observed between 1680 and 1770 and between 1890 and 1980s. Corresponding to the fluctuations of $\delta^{18}O$, there are evident fluctuations in glacial accumulation. The basic trend is that high glacial accumulation corresponds to less negative $\delta^{18}O$ value and low glacial accumulation corresponds to more negative $\delta^{18}O$ value (Table 1), although there are some slight differences in phase. Some features can be recognized from the results:

(a) The cold degrees are different in different cold periods. $\delta^{18}O$ value of −11.4‰ in the coldest stage appeared between 1610 and 1650 in the first cold period that began since 1600 A.D. and it is −9.52‰ in the twentieth century.

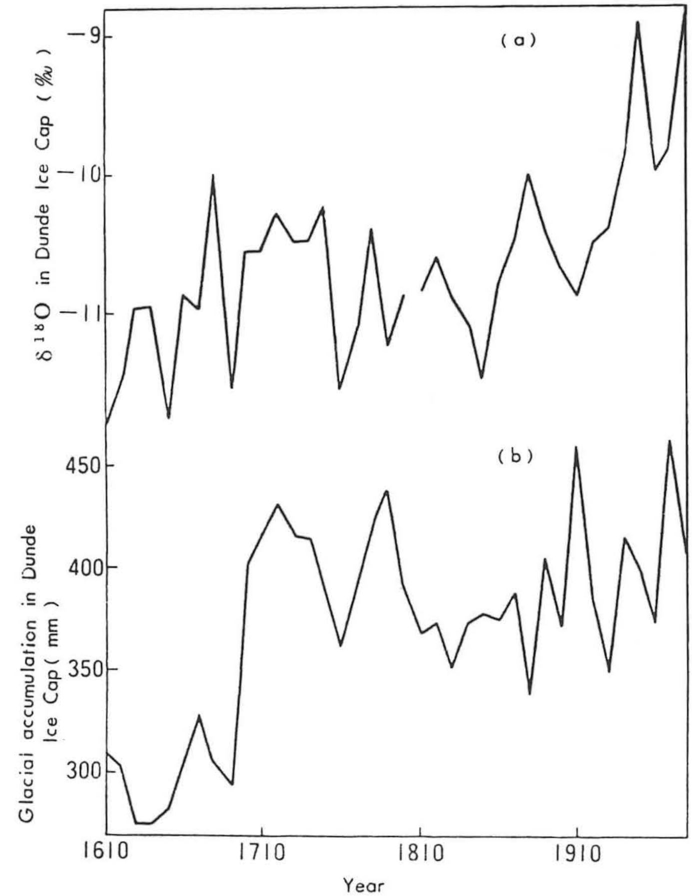

FIG. 1 Temperature ($\delta^{18}O$) and precipitation (glacial accumulation) fluctuations recorded in the Dunde Ice Cap.

TABLE 1 Temperature and precipitation fluctuations indicated by Dunde Ice Core.

Period (years)	Temperature index $\delta^{18}O$ (‰)	Precipitation index Accumulation (mm)
1610-1700	-11.8	276
1710-1800	-10.72	376
1810-1900	-10.73	299
1910-1980	-9.91	351

(b) The temperature indicated by the $\delta^{18}O$ has gradually increased since 1600 A.D. $\delta^{18}O$ value was -10.6‰ in the eighteenth century's warm period while in the warm period of the twentieth century increased to −10.2‰. Dramatic climatic warming happened in the twentieth century, especially in the 1980s.

(c) The lowest glacial accumulation was observed between 1610 A.D. and 1690 A.D. and the highest - in the twentieth century.

DISCUSSION

The long term climatic change in China, especially in the Northwest China, is always an interesting subject for many specialists in earth sciences. Studies in this field have been done with the help of different methods. In the same mountain, where the Dunde Ice Cores were recovered, tree ring studies were undertaken by Zhang Xiangong et al. (1978) and Wang Yuxi et al. (1983). The data series taken for examination was about 1000 years long. Their studies have shown that the tree ring data are representative of temperature in the studied area. If we take the data series corresponding to the period from 1600 A.D. to the present, several cold and warm stages can be recognized. A comparison between the ice core record and the tree ring data (Table 2) shows that the climatic trends from these two sets of data are basically identical. But it is not so clear whether tree rings represent temperature or precipitation. After studying the data in detail, we found that they are more closely related to precipitation (or glacial accumulation) in the Qilian Mountains. From Fig. 2 it is clear that the glacial accumulation in the Dunde Ice Cap and the tree ring data in the Qilian Mountain correlate quite well. In the seventeenth century, the glacial accumulation decreased to around 300 mm (a decrease of 11% as compared to the average). In the eighteenth century, an increase in respect to the average was about 1%. In the nineteenth century decrease values were not so great compared to those of the seventeenth century; there was a 3% decrease in glacial accumulation. In the twentieth century, the highest accumulation appeared in the Dunde Ice Core with an average increase of 14%.

Based on the historic data from East China, Zheng Sizhong et al. (1986) reconstructed the winter temperature in Shanghai since fifteenth century. Taking 10 year average of the Shanghai winter temperature and comparing it with the $\delta^{18}O$ record of the Dunde Ice Core, one may be interested to find that these two records are also basically identical. The identity is even more evident, if the 10 year moving average curves calculated for the Shanghai winter temperature and the Dunde Ice Core record are taken. The only difference is that climatic change in the Dunde Ice Core record happened earlier than the one in the Shanghai winter temperature record, generally from 10 to 20 years earlier.

TABLE 2 A comparison between the Dunde Ice Core record, the tree ring data in the Qilian Mountains, and the records from other sources.

Data source	Periods		
	First	Second	Third
Dunde Ice Core in the Qilian Mts.			
Cold period	1425-1520	1571-1680	1771-1890
Warm period	1521-1570	1681-1770	1891-1980
Tree ring in the Qilian Mts.			
Cold period	1428-1537	1622-1740	1797-1870
Warm period	1538-1621	1741-1796	1871-1923
Winter temperature in Shanghai			
Cold period	?	1576-1690	1781-1895
Warm period	?-1575	1691-1780	1886-1980
Historic data East China			
Cold period	?	1600-1680	1800-1900
Warm period	?-1579	1681-1799	1901-1980

Tang Maocang & Xu Manchun (1984) have also found time difference of modern climatic changes between West China and East China. The possible cause is that the Qinghai-Xizang Plateau (Tibet Plateau) is a trigger region of climatic change. If the cause really exists, the future climatic change in East China can be forecasted based on the present climatic change in West China. Compared to the Dunde Ice Core and the Shanghai winter temperature records, the tree ring record is more closely related to glacial accumulation in the Dunde Ice Core (Fig. 3). The growth of tree ring is controlled both by temperature and by precipitation. Although it is generally believed that the growth rate of tree ring at the lower part of forest reflects precipitation fluctuation and that in the upper limit - temperature fluctuation, but it is possible that the tree rings in the upper part may be influenced by precipitation and those in the lower part - by temperature. Like the tree ring data in the Qilian Mountains, they can be logically explained as precipitation index taking into account their good relation to glacial accumulation in the Dunde Ice Core record. The relationship between tree ring data, which were made by Zhuo Zhengda et al. also in the Qilian

Mountain, and glacial accumulation in the Dunde Ice Core is even more evident (Fig. 4).

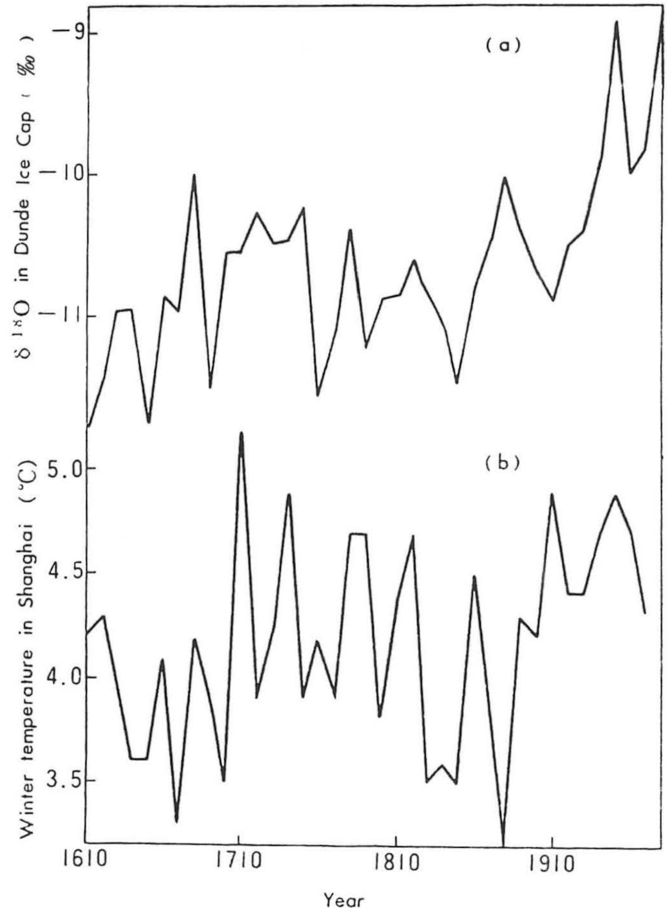

FIG. 2 A comparison between temperature fluctuations deduced from ice core record and historical data.

The most impressive feature of the Dunde Ice Core record since 1600 A.D. is a fast temperature increase in the twentieth century. No matter whether it is the 100 year moving average or the 10 year average curve, this feature is evident or even anomalous. What might be the reason for such a dramatic temperature increase in the twentieth century in this region? The answer may be different from different scientists. An interesting aspect that may concern scientists is whether or not CO_2 greenhouse effect is already recognizable in this region. The temperature increase due to CO_2 greenhouse effect is different according to different models.

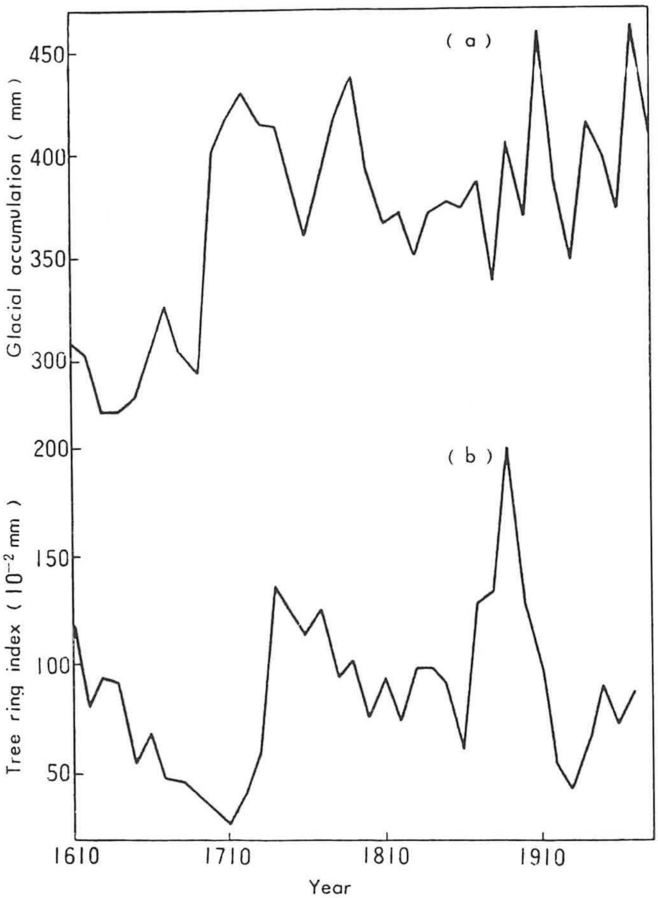

FIG. 3 Glacial accumulation from ice core data and tree ring data in the Qilian Mountain.

Almost all the models reveal that the inland area of middle latitude is sensitive to climatic change and CO_2 greenhouse effect would be first recognizable in this area. The obvious temperature increase indicated by the Dunde Ice Core, therefore, implies the possibility that CO_2 greenhouse effect is already recognizable and that the temperature increase in the area will continue in the near future. We also assume that in this area the temperature ($\delta^{18}O$) increase will in future continue to be accompanied by an increase in precipitation (glacial accumulation.

CONCLUDING REMARKS

It is concluded from the present study that since 1600 A.D. the temperature fluctuations have been basically identical in the whole China, with a slight phase difference between West China and East China and that precipitation fluctuations are basically identical in the Qilian Mountains. The basic feature of the temperature and precipitation fluctuation in the studied area is that temperature decrease is accompanied by low precipitation while temperature increase is accompanied by high precipitation. A possible rise of temperature due to CO_2 greenhouse effect may be accompanied by an increased precipitation.

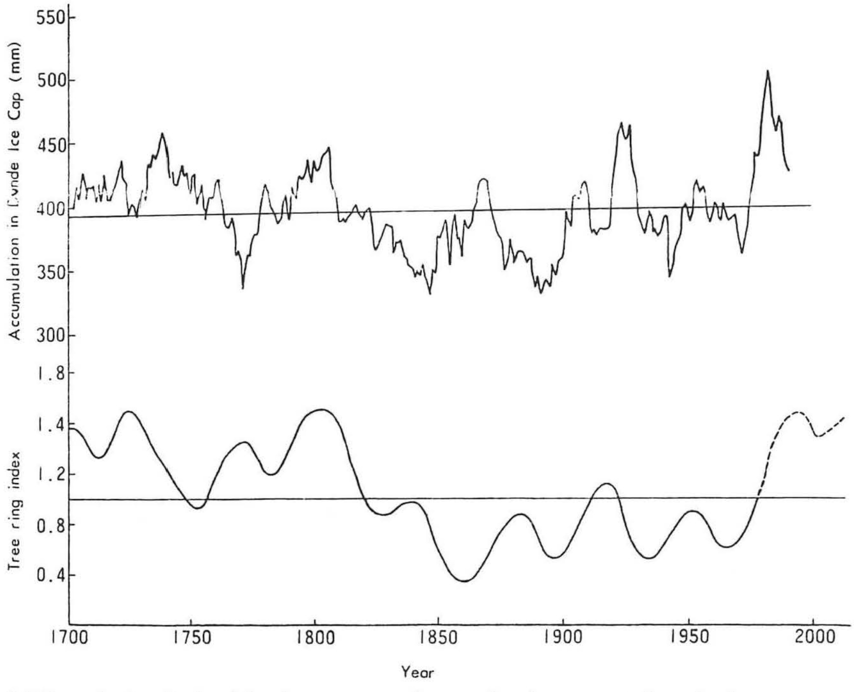

FIG. 4 A detailed comparison between glacial accumulation and tree ring index in the Qilian Mountain.

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