Annals of Glaciology 16 1992
© International Glaciological Society

Trends and features of climatic changes in the past 5000 years recorded by the Dunde ice core

YAO TANDONG
Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, Lanzhou 730000, China

AND L. G. THOMPSON
Byrd Polar Research Center, The Ohio State University, Columbus, OH 43210, U.S.A.

ABSTRACT. A $\delta^{18}O$ record from Dunde Ice Cap, located in the Qilian mountains on the northeastern margin of the Tibetan Plateau, has been analyzed and interpreted. With an ice temperature of −7.3°C at a depth of 10 m and −4.7°C at the bottom of the ice cap, and an accumulation rate of 400 mm a^{-1}, the Dunde core has provided interesting results. The upper part of this core, core D-1, can be easily dated by a combination of $\delta^{18}O$, microparticle concentration and conductivity. It can also be dated as far back as 4550 BP by counting dust layers in ice. Based on the time scale established by the above methods and on the $\delta^{18}O$–temperature relation, the $\delta^{18}O$ fluctuations in the upper 120 m of the core can be interpreted as mainly due to climatic changes during the past ~5000 years. The warmest periods in the past ~5000 years in the core were found to be centered on the present, 3000, and 4100 BP, and the colder periods center around 500, 1200, 4000, and 4500 BP. It is clear from the ice-core record that the Little Ice Age was only one of many cold periods in the past, although it was the coldest period in the past 500 years.

INTRODUCTION

The Dunde ice core was recovered from Dunde Ice Cap, which is located in the Qilian mountains on the northern margin of the Tibetan Plateau (38°6′ N, 92°24′ E, see Fig. 1). The ice cap has an area of 60 km^2 and a summit elevation of 5325 m. The ice temperature at a depth of 10 m is −7.3°C. At the bottom (139.8 m below surface) it is −4.7°C.

Three cores to bedrock were recovered from the ice-cap summit. Core D-1 (139.8 m), Core D-2 (136.6 m) and Core D-3 (138.4 m). Thompson and others (1989, 1990), Xie and others (1989) and Yao and others (1990) have already reported on the field sampling, analysis procedure, and major results of the core analyses.

The present paper focuses on results relating to climatic change in the past 5000 years, as recorded in Core D-1, and the discussion is based on the $\delta^{18}O$ results from that core.

CLIMATIC PARAMETERS FROM DUNDE ICE CORE

Oxygen-18 ($\delta^{18}O$) has been measured on the Dunde ice core for use as a climatic parameter. Although there are some limitations, it is still effective to use a $\delta^{18}O$–temperature relationship to reconstruct past climatic conditions in polar regions. However, in the middle latitudes, the transportation history of water-vapor sources is more complicated. It is, therefore, necessary to clarify some key issues. The most important is whether or not $\delta^{18}O$ variations are representative of temperature variations. In 1990, primary research relating to this was

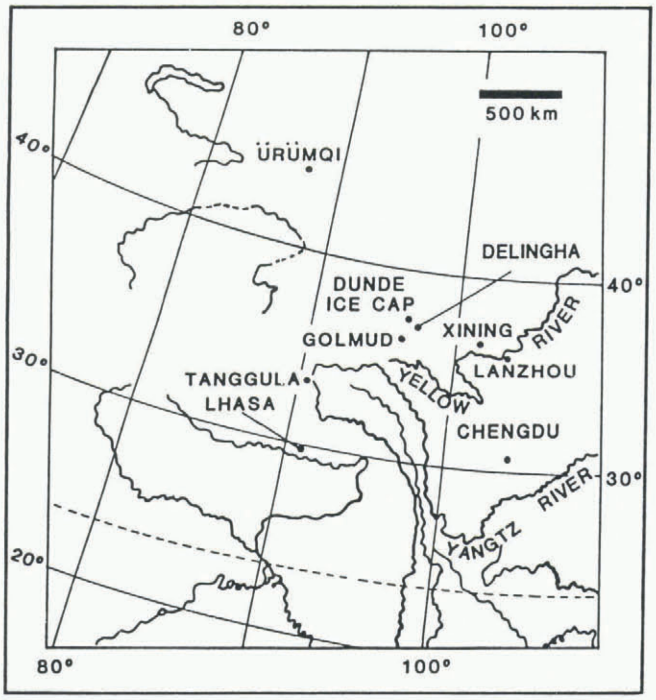

Fig. 1. Location of Dunde Ice Cap.

https://doi.org/10.3189/1992AoG16-1-21-24 Published online by Cambridge University Press

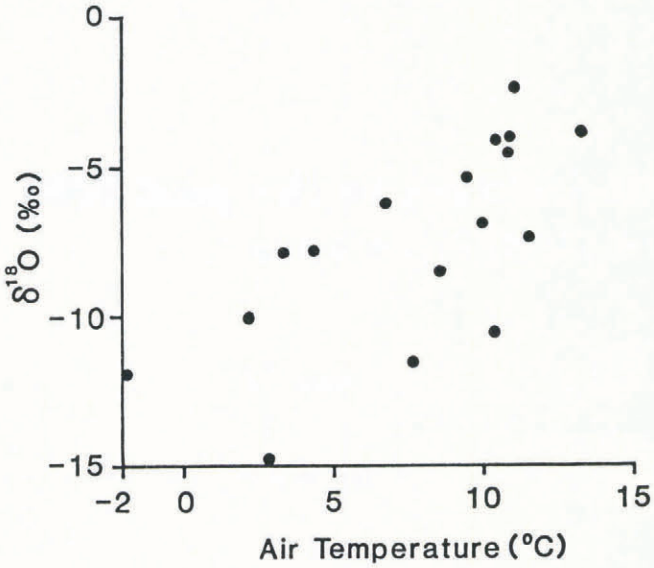

Fig. 2. Relation between $\delta^{18}O$ and air temperature measured at Delingha Meteorological Station.

conducted at Delingha Meteorological Station, 150 km from Dunde Ice Cap (Fig. 1). Snowfall and precipitation samples were collected between February and September 1990. Analyses of these samples indicate that there is an obvious relationship between $\delta^{18}O$ and air temperature, although more data are needed to establish the $\delta^{18}O$–temperature relationship quantitatively. The primary data show an approximately linear relationship between $\delta^{18}O$ and air temperature (Fig. 2). Also important is the fact that over 80% of the annual precipitation on Dunde Ice Cap falls in the summer. The $\delta^{18}O$ values of the Dunde core, therefore, reflect mainly summer atmospheric conditions.

DATING THE ICE CORE

Dating of the ice core was accomplished with the use of several techniques. The upper 60 m of the core were dated by using three parameters which can distinguish seasonal variability. These parameters are $\delta^{18}O$, microparticle concentration, and conductivity. By using a combination of such parameters that exhibit seasonal cycles, ambiguous features can be clarified. Figure 3 gives an example of the ice-core dating by this method.

The lower part of the core, below 60 m, was only dated by counting dust layers in the core. Generally one dust layer forms each year, associated with strong winds or dust storms and with intense summer radiation. Thus the dust layers were interpreted to be annual. The depth to which this method can be used is 117 m and the total number of years is 4550. Below 60 m, the uncertainties in dating are about ±10 years between 60 and 105 m, ±15 years between 105 and 110 m, +20 years between 110 and 115 m, and close to ±40 years at a depth of about 117 m.

THE DUNDE ICE-CORE OXYGEN ISOTOPE RECORD DURING THE PAST 5000 YEARS

Figure 4a shows the $\delta^{18}O$ record from the Dunde ice core over the past ~5000 years. The $\delta^{18}O$ record is a 10 point moving average of 10-year average values, and thus smooths out short-term events less than 100 years in duration. The average $\delta^{18}O$ value is −10.8‰ over the past 5000 years. If periods when $\delta^{18}O$ is less negative than −10.8‰ are interpreted as warm periods and ones when $\delta^{18}O$ is more negative than −10.8‰ as cold periods, then

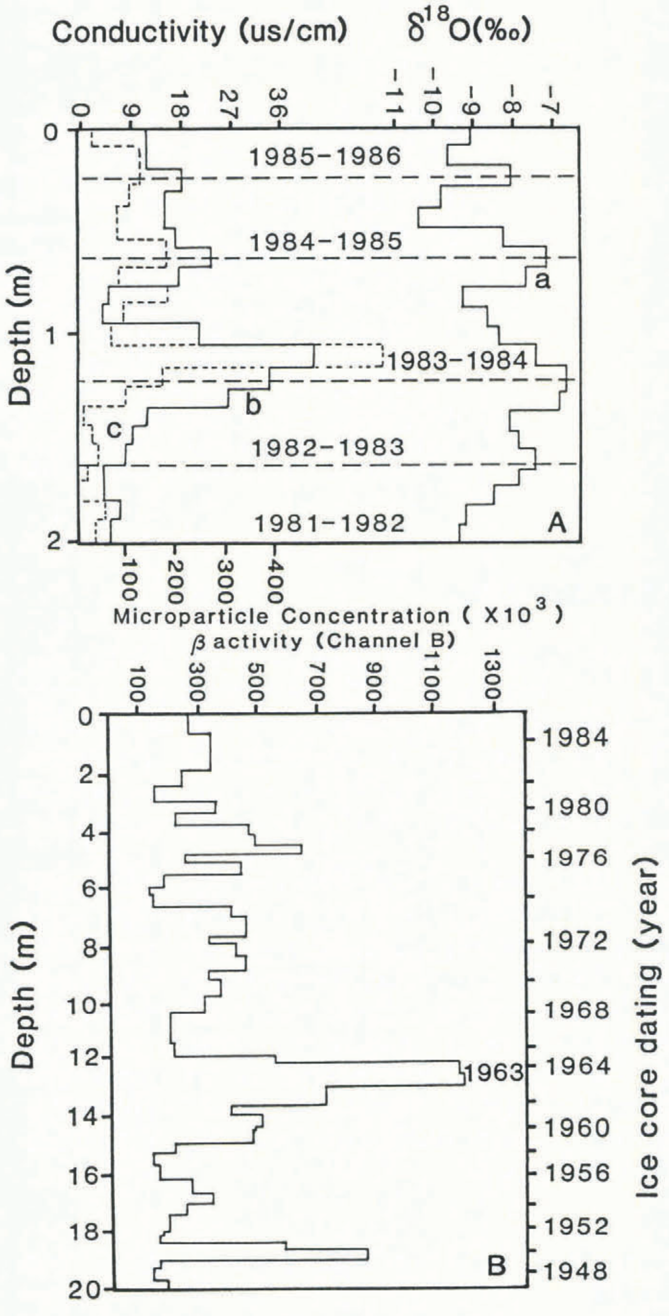

Fig. 3. A. An example of dating the Dunde ice core by combining oxygen isotope, microparticle concentration, conductivity, and β activity data. Line a is $\delta^{18}O$, b is microparticle concentration, and c is conductivity. B. The date determined by the method shown in A agrees well with the date determined by the β activity peak.

https://doi.org/10.3189/1992AoG16-1-21-24 Published online by Cambridge University Press

the warmest periods in the past 5000 years are the present, 2600 to 3600 BP, and 4000 to 4200 BP. Using a 50 a average, the present is the warmest period recorded in the ice core. Using a 100 a average, the warm period at present is just slightly warmer than that ~3000 BP. The coldest periods are 800 to 1100 BP, 1300 to 1400 BP, 3900 to 4000 BP and 4400 to 4550 BP.

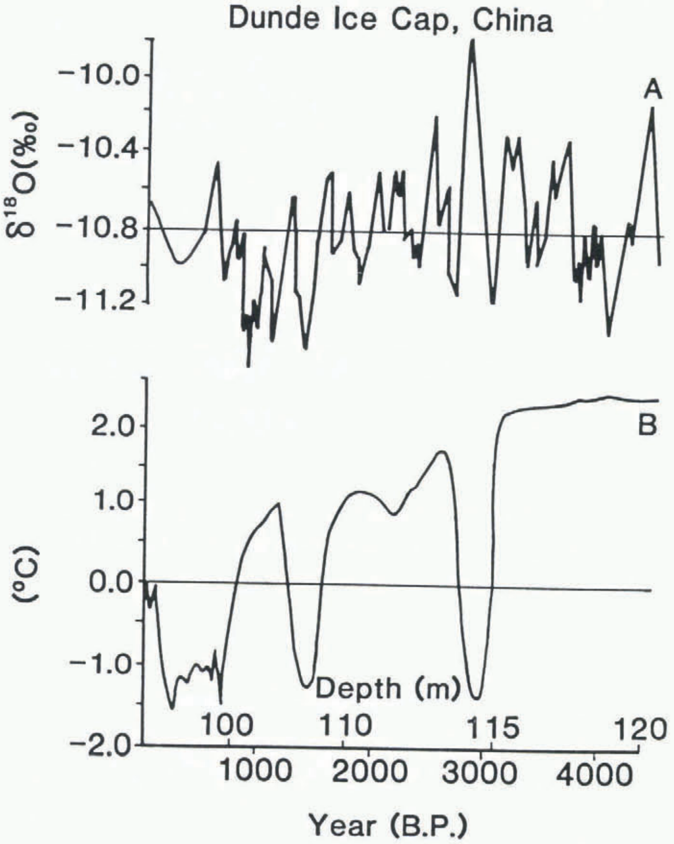

Fig. 4. (a) Oxygen isotope record from Dunde ice core, and (b) comparison with the paleotemperature record from Zhu (1973).

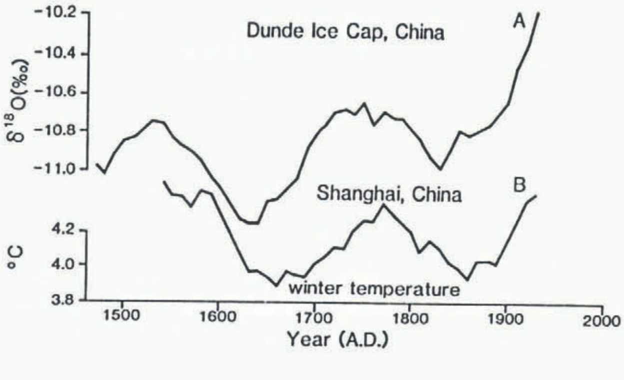

Fig. 5. The Dunde ice-core $\delta^{18}O$ record (A) compared with the Shanghai winter temperature record, (B). The two records are well correlated if the phase difference is taken into consideration.

The record shows that before ~3000 BP the climate was characterized by a general warming trend, while after ~3000 BP it was characterized by cooling, especially in the period around 900 BP (1000 AD). The Dunde oxygen isotope record indicates that the Little Ice Age was only one of many cold periods in the past 5000 years.

It is generally assumed that the climate before ~3000 BP was characterized by high temperatures. However, it is clear from the Dunde record that there were cold and warm climatic fluctuations before ~3000 BP. From 5000 to ~3000 BP, long periods, lasting over 100 years, were characterized by a cold climate. It is clear from Figure 4 that 700 BP was a relatively warm period. Historic data have recently revealed this warm period in eastern China also (Man, 1990).

COMPARISON WITH OTHER RECORDS

Although a number of studies have been done to trace the climatic changes in the past 5000 years in China, the paleotemperature record established by Zhu (1973) is still the most authoritative. Another important study of climatic change during the past 500 years was made by Zhang (1978), based on winter temperatures in Shanghai obtained from historical documents. It is, therefore, reasonable to compare these records (Fig. 4b) with that from the Dunde core. Some important features can be seen in these comparisons.

(1) Similar trends of climatic change can be recognized in Dunde records and in Zhu's records (Fig. 4). Beginning ~3000 BP, the climate tended to cool with several fluctuations, reaching one of the coldest periods about 900 BP, and then began to warm except for the cold period of the Little Ice Age.
(2) Both the Dunde and Zhu's records indicate that, although it was the coldest period in the past 500 a, the Little Ice Age was only one of many cold periods in the past 5000 a.
(3) Figure 5 compares a 10 point moving average of the 10 year average $\delta^{18}O$ record in the Dunde core with Zhang's record. There are two obvious cold periods and three warm periods since ~550 BP (1450 AD) in both records, but there is a phase shift such that the peaks and troughs in the Dunde record are ~20 a earlier than in the Shanghai record. Tang (1984) also found such a phase shift in climatic change between western and eastern China. He suggested that the Tibetan Plateau may be a trigger region for climatic change.

Jones and others (1986) established a temperature time series for the Northern Hemisphere from records of meteorological instruments. Figure 6 compares the Dunde $\delta^{18}O$ record with that of Jones and others. The trends of the two records are comparable.

Stable isotope records from ice cores have been obtained from the Arctic and the Antarctic. Considering the location of Dunde Ice Cap, it is more logical to compare the Dunde record with that from the Arctic. Thus in Figure 7 we compare the Dunde $\delta^{18}O$ record with that from Camp Century since 800 BP (1200 AD)

https://doi.org/10.3189/1992AoG16-1-21-24 Published online by Cambridge University Press

(Dansgaard and others, 1971). It is clear that the trends are basically identical in the two cores. Temperatures began to increase ~1250 AD, and reached a maximum ~1360 AD. Thereafter, temperatures decreased to the first minimum of the past 500 years, around 1650 AD. There was then a relatively warm period from 1700 to 1800 AD. The cold period ~1840 AD is the last evident cold period in these two records. These two ice cores have recorded a significant temperature increase in the 20th century. However, the increase in the Dunde record, from the center of the world's largest continent, is significantly greater.

CONCLUSIONS

By combining several parameters, a time scale has been established for the Dunde ice core. Based on the study of the $\delta^{18}O$–temperature relationship, the $\delta^{18}O$ record of the Dunde core has been interpreted as mainly one of temperature change. More work is necessary over the vast Tibetan Plateau in order to establish the present $\delta^{18}O$–temperature relationship better.

A large amount of climatic information has been provided by the Dunde ice core. The present paper discusses only the climatic information from the $\delta^{18}O$ record of the past 5000 years. Approximately 3000 BP is a climate boundary; the record is characterized by increasing temperatures before, and decreasing temperatures after, this time.

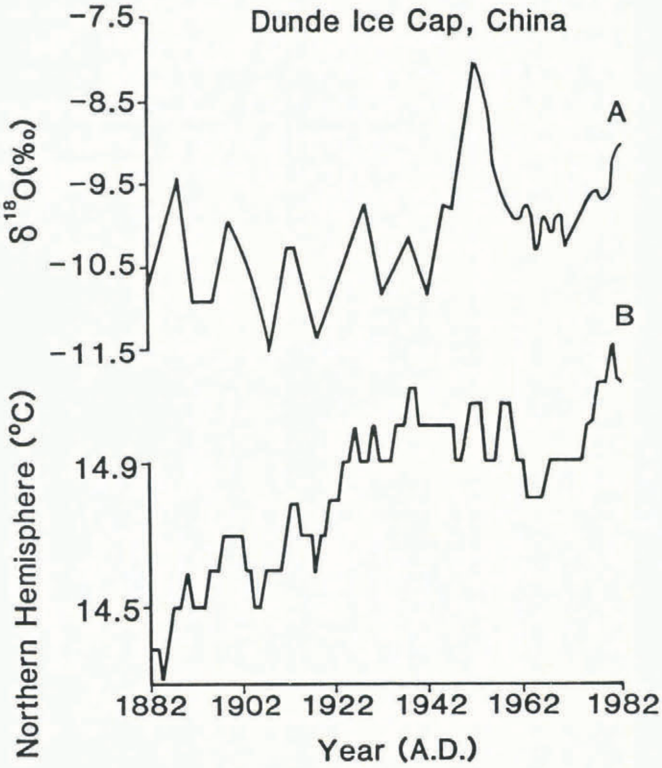

Fig. 6. Comparison between the Dunde ice-core record (A) and the Northern Hemisphere temperature record of Jones and others (1986) (B).

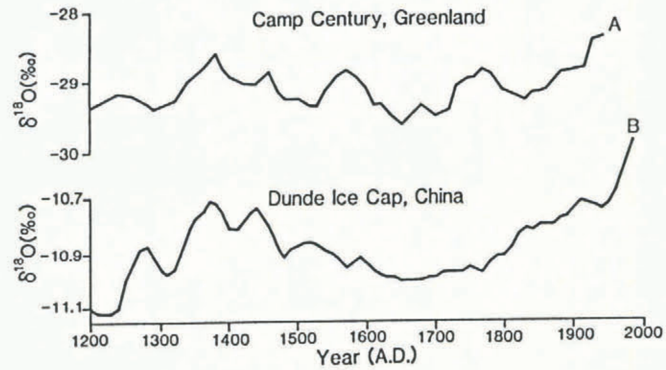

Fig. 7. The Dunde ice-core record (A) and the Camp Century ice-core record (B) show similar trends.

REFERENCES

Dansgaard, W., S.J. Johnsen, H.B. Clausen and C.C. Langway, Jr. 1971. Climatic record revealed by the Camp Century ice core. *In* Turekian, K.K., *ed. The Late Cenozoic glacial ages*. New Haven, CT, and London, Yale University Press, 37–56.

Jones, P.D., T.M.L. Wigley and P.B. Wright. 1986. Global temperature variations between 1861 and 1984. *Nature*, **322**(6078), 430–434.

Man, Z.M. 1990. Geographical shift in east China during a warm period in the 13th century A.D. *In* Yageng, S., M. Wang, P. Zhang and X. Zhao, *eds. Progress in studies of climate and sea level (I)*. Ocean Press, 20–22. [In Chinese.]

Tang, M. 1984. Climatic change in the Qilian mountains. *Plateau Meteorology*, **3**, 21–33. [In Chinese.]

Thompson, L. *and 9 others*. 1989. Holocene–Late Pleistocene climatic ice core records from the Qinghai-Tibetan Plateau. *Science*, **246**(4929), 474–477.

Thompson, L. *and 9 others*. 1990. Glacial stage ice-core records from the subtropical Dunde ice core. *Ann. Glaciol.*, **14**, 288–297.

Xie, Z., X. Wu, T. Yao and L. Thompson. 1989. A primary study of paleoclimate and paleoenvironment from Dunde ice core. *Quaternary Sciences*, **2**, 135–142. [In Chinese with English abstract.]

Yao, T., Z. Xie and L. Thompson. 1990. Little Ice Age recorded by Dunde Ice Cap. *Sciences in China*, 1197–1201.

Zhang, D. 1978. A primary analysis of winter temperature in the past 500 years in south China. *In Proceedings of Symposium on Climatic Change in China*. Beijing, Science Press, 64–70. [In Chinese.]

Zhu, K. 1973. Climatic changes in the past 5000 years in China. *Sci. Sin.*, **3**, 1–5. [In Chinese.]

The accuracy of references in the text and in this list is the responsiblity of the author/s, to whom queries should be addressed.

https://doi.org/10.3189/1992AoG16-1-21-24 Published online by Cambridge University Press