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# Temperature Variations on the Tibetan Plateau During the Last Millennium

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**Abstract:** Temperature variations on the Tibetan Plateau during the last millennium are revealed by comparing a Qamdo tree-ring $\delta^{13}C$, the Dasuopu ice-core $\delta^{18}O$ series, and a previous composite temperature reconstruction. Results show that an obvious warm period during 1200−1400 AD corresponds to the Medieval Warm Period (MWP) when summer temperature was 1.2℃ higher than the recent 1000 years average, and a cool phase from 1400 to 1700 AD, with summer temperature being 0.5℃ lower than long-term average, can be correlated to the Little Ice Age (LIA). The 13th century was the warmest phase during the past 1000 years, while the coldest period occurred during 1000−1200 AD. The 20th century warming was characterized by rapid winter temperature rise while summer temperature at that time displayed a slight downward trend.

**Key words:** Tibetan Plateau; temperature change; tree ring; ice core; stable isotope

## Introduction

The reconstruction of long climatic series spanning the past few centuries and millennia is important both for understanding natural climate variations at those timescales and for estimating anthropogenic influence on the climate system. Our present view of past climatic conditions, however, is mainly gained from proxy data series from high latitudes of both hemispheres. To test and validate climatic models on a global scale, it is essential to expand this database to all regions of the Earth's surface. In the last decade, many achievements have been made in China in terms of local climate reconstructions, integrated multi-proxy studies and climate modeling [1−12]. However, our knowledge of past climatic change in western China, especially in the Tibetan Plateau, is still debatable due to low time resolution and uncertainties in the climate forcing of some proxy records [13]. Therefore, in order to gain a better understanding of temperature changes in the Tibetan Plateau during the last millennium, the present study compared the palaeoclimatic information contained in tree rings from the Qamdo region (31° N, 96° 58′ E), in the Dasuop ice cores (28° 23′ N, 85° 43′ E), and in a previous temperature reconstruction complied by Yang Bao *et al.* [13]. We pay special attention to climatic characteristics during the MWP, the LIA and in the 20th century.

## 1 Temperature sensitivity of proxy records

Tree-ring samples in the Qamdo region were taken near or at the alpine timberline. Thus it is estimated that $\delta^{13}C$ values mainly represent temperature variations of the growing season. The $\delta^{13}C$ chronology has a resolution of 5 years and each value is derived from averaging at least measurements of 3 samples. Here we used decadal $\delta^{13}C$ series for comparison. The anthropogenically induced increase in atmospheric $CO_2$ partial pressure since ca. 1800 AD and the related $\delta^{13}CO_2$ decrease in the atmosphere resulted in a remarkable declining trend in $\delta^{13}C$ in wood cellulose, which hampers reliable calibration with recent climate data spanning the past 50 years. To remove this long-term trend, first-order differences of $\delta^{13}C$ values were

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used to investigate the correlation with the meteorological observations during 1950−1994 [14]. The tree-ring $\delta^{13}C$ differences show very high correlations with summer (June−August; $r = 0.67$; $p < 0.01$) and growing season (May−September; $r = 0.59$; $p < 0.01$) temperature variations at Qamdo. The correlation with the annual mean temperature of the Qamdo region is also significant on the 95% confidence level. It is noteworthy that the $\delta^{13}C$ differences are also closely correlated ($r=0.56$, $p<0.001$) with the temperature averages of the whole Tibetan Plateau, which were derived as a mean from 78 meteorological stations. This suggests that the Qamdo tree-ring $\delta^{13}C$ series not only represents temperature change during the summer half-year of the Qamdo region, but also to a great extent is a good indicator of summer temperature change over the whole Tibetan Plateau.

The Dasuopu ice-core $\delta^{18}O$ values are mainly influenced by the "amount effect" of isotope fractionation on seasonal and annual timescales and consequently reflect precipitation fluctuations on short-term time scales. On decadal to centennial time scales, however, $\delta^{18}O$ values in the Dasuopu ice core principally reflect atmospheric temperature change [16]. A comparison with other high-resolution monsoon proxy records from the Arabian Sea and south Oman shows that there is good agreement between them, and that there is closer correlation between the Dasuopu ice-core $\delta^{18}O$ and south Oman marine record whereas the latter serves as a record for the large-scale thermal contrast between the Tibetan Plateau and the Arabian Sea. This provides further evidence that the low-frequency $\delta^{18}O$ variation of the Dasuopu ice core is an indicator of temperature change [17].

## 2 The MWP and LIA on the Tibetan Plateau

The tree-ring $\delta^{13}C$ is affected by increasing atmospheric $CO_2$ due to human activities during the past two centuries and consequently exhibits considerable deflection from natural variations. Therefore, we only regard here the $\delta^{13}C$ variations during 1000−1800 AD. According to Helle *et al.* [14], the $\delta^{13}C$ mean during 1000−1800 AD is basically equal to the average of the whole series and reflects the present average temperature. Therefore we computed the departures of tree-ring $\delta^{13}C$ and ice-core $\delta^{18}O$ series for comparison (Fig. 1).

As stated above, the Qamdo tree-ring $\delta^{13}C$ as well as the Dasuopu ice-core $\delta^{18}O$ series is indicative of large-scale temperature change and the former is calibrated by modern temperature observations. Therefore we compare them with the previous temperature reconstruction of Yang Bao *et al.* [13] for the whole Tibetan Plateau. This temperature composite was derived from ice cores, tree rings, and lake sediments. The Dasuopu ice-core $\delta^{18}O$ series was included in the original temperature reconstruction of Yang Bao *et al.* [13] composite. In order to hold these series independent, we removed the Dasuopu series again from the previous temperature composite to derive a new temperature reconstruction for the Tibetan Plateau. The new temperature reconstruction (Fig. 1c) is very similar to the previous composite.

As viewed from Fig. 1, the Qamdo tree-ring $\delta^{13}C$ and Dasuopu ice-core $\delta^{18}O$ series show high similarity on decadal and interdecadal timescales. The correlation coefficient between them is 0.31, which is significant at the 95% confidence level. Both series show that the period from 1000−1200 AD was the coldest period during the last 1000 years. The new Tibetan Plateau temperature composite (Fig. 1c) and the Qamdo tree-ring $\delta^{13}C$ shows corresponding events. They indicate the cold period during 1000−1150 AD, the MWP during 1200−1400 AD, and the LIA from 1400 AD to 1700 AD. The difference is that the Qamdo tree-ring $\delta^{13}C$ and the temperature composite of the whole Plateau exhibit that the 13th century was the warmest stage while the Dasuopu $\delta^{18}O$ series indicates that the warmest episode occurred in the late 17th century. Regardlessly, the

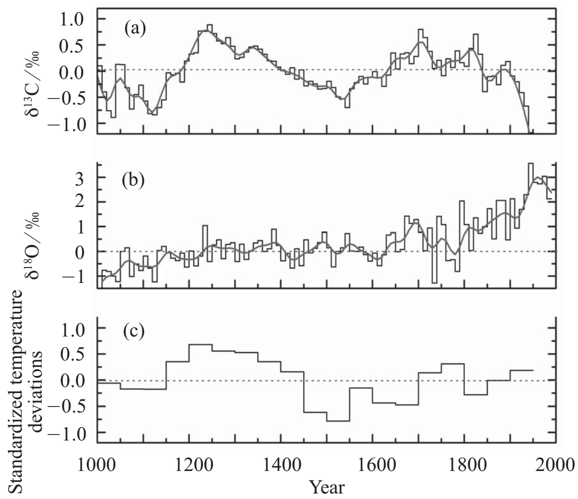


Fig. 1 1000-year temperature changes (relative to 1000−1800 AD) indicated by different proxy records (The superimposed smoothed curves are derived by Fast Fourier Transform filtering to emphasize long-term fluctuations)
(a) Qamdo tree-ring $\delta^{13}C$ [14], (b) Dasuopu ice-core $\delta^{18}O$ [15], (c) temperature reconstruction for the whole Tibetan Plateau with exclusion of Dasuopu ice-core $\delta^{18}O$ series

broad similarities among the three independent series show that they are good indicators of temperature change for the Tibetan Plateau.

Based on the calibration equation between the Qamdo tree-ring δ$^{13}$C and temperature, we attempted to quantify the amplitude of average temperature change during the last 1000 years. In Qamdo/ the whole Tibetan Plateau, the MWP was warmer than the 20th century by 1.6℃/1.2℃ and the 13th century even warmer by 2.3℃/1.6℃. The LIA was 0.7℃/0.5℃ cooler than present. The estimated coldest temperature from 1000 AD to 1200 AD in Qamdo/ the whole Tibetan Plateau was 1.5℃/0.9℃ lower than the long-term average. Besides, based on the data obtained from snow line changes on the eastern fringe of the Tanggula Range, it is estimated that local temperatures during the Neoglacial Period (here defined as the period 3000−1000 a BP) and during the LIA might be 1.0−1.9℃ and 0.6−1.2℃ lower than the modern temperature, respectively. Temperature fluctuations in other places of the Tibetan Plateau indicated by fluctuations of the marine glaciers are within the same range of temperature change [18]. These temperature estimates are basically consistent with our inferences.

## 3 The 20th century warming on the Tibetan Plateau

In order to remove the non-climatic effect of changes in the $CO_2$ partial pressure on the long-term δ$^{13}$C trend in the tree-ring series, Helle *et al*. [14] tested several methods and concluded that the summer temperature of the Tibetan Plateau shows a gradually downward trend, which is corroborated by new δ$^{13}$C series from the same study site (Griessinger, 2006, personal communications). In contrast, an accelerating warming trend is presented by the changes of the Dasuopu ice-core δ$^{18}$O series during past two centuries. This trend is particularly apparent in the 20th century. Modern temperature observations show that a rapid rising trend occurred in the recent 40 years, which was predominantly caused by an increase in winter temperatures, whereas summer temperatures only had a slight rise [19]. Recent studies show that winter precipitation δ$^{18}$O in the Dasuopu ice core displayed a marked upward trend during 1800−1996, whereas summer precipitation δ$^{18}$O had a slightly downward trend [20]. If we also regard the summer precipitation δ$^{18}$O record in the ice core as an indicator of temperature, it is consistent in variation trend with summer temperature change reflected by the Qamdo tree-ring δ$^{13}$C. Here it is noteworthy that amplitudes of seasonal δ$^{18}$O variations in the ice core might be affected by annual layer thinning rates and the number of samples. This might mask trend signals of summer and winter precipitation δ$^{18}$O records to some extent. However, summer and winter precipitation δ$^{18}$O values fluctuated around two remarkably different mean values and varied in large amplitudes during the 20th century. Therefore it can be inferred that the influence of annual layer thinning rates and the number of samples on variation trends displayed by seasonal δ$^{18}$O records is negligible. Thus we suggest that winter temperature has an obvious rising trend while summer temperature displays a slight decrease trend in the last 100 years. The 20th century warming in the Tibetan Plateau is therefore predominately exhibited in winter temperature change.

## 4 Conclusions

Based on the Qamdo tree-ring δ$^{13}$C, the Dasuopu ice-core δ$^{18}$O and previous composite temperature reconstruction for the Tibetan Plateau, together with other types of proxy data, we made an analysis of temperature change on the Tibetan Plateau during the last millennium. This work provides a basis for further integrated study of climate change. The following conclusions can be drawn:

(1) There exist correlative periods for the MWP and LIA on the Tibetan Plateau, which occurred in 1200−1400 AD and 1400−1700 AD, respectively.

(2) Average summer temperature on the Tibetan Plateau during the MWP was up to 1.2℃ higher than at present. The warmest period during the past 1000 years occurred in the 13th century, when summer temperature was 1.6℃ higher than at present.

(3) Average summer temperature on the Tibetan Plateau during the LIA was about 0.5℃ lower than at present. The coldest period of the last millennium occurred during 1000−1200 AD, when summer temperature in the Qamdo region was about 1.5℃ lower than at present.

(4) The 20th warming on the Tibetan Plateau is mainly attributable to the rising winter temperature, whereas summer temperature shows a slight decreasing trend.

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