ARTICLE IN PRESS

Palaeogeography, Palaeoclimatology, Palaeoecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Warming and wetting climate during last century revealed by an ice core in northwest Tibetan Plateau

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ARTICLE INFO

Keywords:
Ice core record
$\delta^{18}O$
Annual accumulation
Warming-wetting climate
Westerlies
Northwest TP

ABSTRACT

Glaciers on the Tibetan Plateau (TP) exist in different states of extension and retreat, responding to the westerly winds and Indian monsoon. However, few studies to-date have focused on climate change in the westerlies-dominated northwest TP. Here, we report an ice core climate record during the last century retrieved from the Kuokuosele (KKSL) Glacier in the westerlies-dominated eastern Pamir, northwest TP. The ice core has dated based on annual layer counting using ice core $\delta^{18}O$ seasonal cycles, constrained by both the beta (β) activity peak and ^{137}Cs concentration peak in 1962/63. Reconstruction of $\delta^{18}O$ and annual accumulation from the ice core and comparison with observed temperature and precipitation at nearby meteorological stations as well as CRU (Climate Research Unit) data confirm their climatic and regional significance. Both ice core $\delta^{18}O$ and accumulation increased during the last century, thus pointing to a warming and wetting trend in the westerlies dominated northwest TP.

1. Introduction

With an average altitude above 4000 m, the Tibetan Plateau (TP) and its surroundings contain the largest number of glaciers outside the Polar Regions (Yao et al., 2012). These glaciers are largely retreating, with significant impacts on regional water resources as an unambiguous sign of global warming (Yao et al., 2004, 2007, 2012; Wang et al., 2006; Immerzeel et al., 2010; Bolch et al., 2012). Climate on the TP is affected by both the westerlies and Indian monsoon (Bothe et al., 2011; Yao et al., 2012). In the past several decades, precipitation is increasing in the westerlies-dominated region, but decreasing in the monsoon-dominated region, which has resulted in a heterogeneous status of the glaciers in the TP responding to climate warming (Yao et al., 2012, 2017; Yu et al., 2013). Furthermore, the most recent glacier collapse in the westerlies-dominated Aru region in the northwest TP might be a warning of the hazardous consequences of glacier retreat due to climate change, more specifically the warming and wetting climate (Tian et al., 2017). However, the increasing trend of the westerlies over the TP can only be identified during the last ~30–40 years due to the limited meteorological data available, which emphasizes the necessity of reconstruction of longer climate records based on paleo-climate proxies with proven climate significance and higher temporal resolution. At present, it is most important to reconstruct the climate change during the last century which is a time window focusing on global warming and heterogeneous glacier status in the TP and its surroundings.

Stable oxygen isotope ($\delta^{18}O$) and annual accumulation in ice cores are interpreted as proxies for temperature and precipitation, respectively, in the TP. Since the 1980s, several ice cores have been recovered from the TP, and climate change relating with the Indian monsoon were intensively studied (Yao et al., 1997a, 1997c; Qin et al., 2000; Thompson et al., 2000b, 2006; Kaspari et al., 2007; Zhang et al., 2007; Grigholm et al., 2009; Xu et al., 2009; Yang et al., 2011; Zhao et al., 2012; Gao et al., 2015; Kang et al., 2015). However, there were few studies on the westerlies in the northwest TP. A new ice core extracted from the eastern Pamirs in the northwest TP by the ice core drilling team of the Institute of Tibetan Plateau Research, CAS (ITPCAS), has made it possible to reconstruct the climate change history and to discuss the temperature and precipitation variability during the last century in the westerlies-dominated northwest TP.

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http://dx.doi.org/10.1016/j.palaeo.2017.09.009
Received 9 January 2017; Received in revised form 2 September 2017; Accepted 7 September 2017

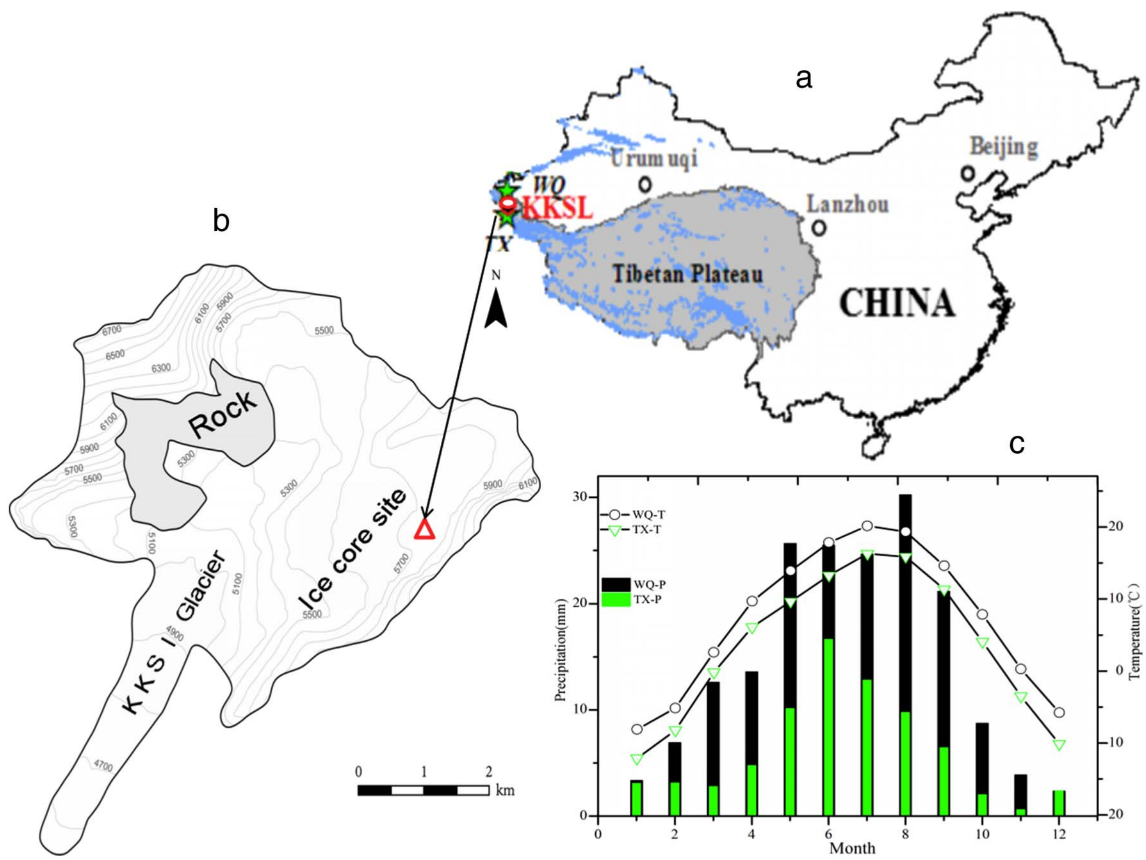

Fig. 1. Location of the KKSL ice core over the KKSL Glacier and climate condition in the eastern Pamir. In the Figure, (a) stands for the locations of the KKSL Glacier (circle) and nearby meteorological stations (asterisk), (b) for the location of the KKSL ice core drilling site (trangle), (c) for the temperature and precipitation seasonality at Taxkorgan and Wuqia stations. KKSL stands for Kuokuosele, TX for Taxkorgan, WQ for Wuqia.

2. Methods and data

2.1. Ice core recovery

The Kuokuosele (KKSL) Glacier (38°11.572′ N,75°10.965′ E, 5700 m a.s.l.) is located in the eastern Pamir in the northwest TP (Fig. 1a), where exists > 139 glaciers with a total area of 257.93 km^2 (Su and Liu, 1989). The drill site on the KKSL Glacier is selected on a flat platform (Fig. 1b). The flat platform is located between 5500 m a.s.l. and 5900 m a.s.l. extending from northeast to southwest with an area of about 4km^2. Topographically, the platform is ideal for ice core recovery.

Fig. 1c shows the temperature and precipitation seasonality at the two nearest stations Wuqia (WQ; 39°25.8′N,75°9′E, 2175 m, ~137.4 km) and Taxkorgan (TX; 37°47′N,75°14′E, 3100 m, ~45.85 km). The annual temperatures are 7.3 °C and 3.5 °C at WQ and TX during 1957–2010, respectively. The temperature lapse rate between the two stations is calculated as 0.41 °C/100 m based on the temperature and elevation differences. Using the lapse rate, we can estimate an annual air temperature of −7.1 °C at the drill site of 5700 m a. s. l. The actual measurement of the ice temperature at 10 m depth, which is considered as annual air temperature at the drill site (Tsushima et al., 2015), is −8.8 °C. The similar results between the estimated annual air temperature using lapse rate and measured annual air temperature at the drill site further confirm that the KKSL glacier is a cold glacier, and is identical with conclusion of previous studies (Yu et al., 2006; Holzer et al., 2015). The all above information verifies that the KKSL glacier is suitable for ice core climate reconstruction.

A 170.42 m ice core was extracted from the KKSL Glacier (Fig. 1b, the glacier map is from "The State Bureau of Surveying and Mapping") in June 2012. The present study focuses on reconstructing climate change during the last century corresponding to the upper 47.45 m of the ice core.

2.2. Sample preparation and analysis

After recovery, the ice cores were transported in frozen state to a cold room with temperature lower than −20 °C. The ice cores were cut into 930 continuous samples at 5 cm intervals for the upper 47.45 m of the ice core in the cold room. They were melted at room temperature for δ^{18}O measurement.

After complete melting, the water samples for δ^{18}O measurement were filtered (0.22 µm), put into 2 ml vials and measured by Picarro L2130-I (USA Wave Scan-Cavity Ring Down Spectrometer with an accuracy of ± 0.05‰ for δ^{18}O) at ITPCAS. The results were expressed relative to the Vienna Standard Mean Ocean water (VSMOW).

Samples for the beta(β) radioactivity and ^{137}Cs concentrations were also melted at room temperature. Beta(β) radioactivity measurement were performed on a Mini 20Alpha-Beta Multidetecter (French Eurisys Mesures Corporation) with no contamination indicated by analysis of the field blanks. The background is 0.08–0.22, which is well below the actual value of β activity. The ^{137}Cs concentrations were measured by ORTEC (GWL-120-15) - HPGe (USA, High Purity Germanium Gamma Ray Spectrometer with an accuracy of 0.01).

2.3. Ice core dating

Based on the seasonal variations of δ^{18}O in the KKSL ice core, we have counted annual layers between troughs which correspond to winter values and thus the beginning of a new accumulation year. The annual layer counting approach based on δ^{18}O in the upper 47.45 m yielded a time series during the last century. To further constrain the ice