Quaternary Science Reviews 178 (2017) 14–23

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Contrasting early Holocene temperature variations between monsoonal East Asia and westerly dominated Central Asia

Jiaju Zhao [a], Chen-Bang An [a, *], Yongsong Huang [b, d, **], Carrie Morrill [c], Fa-Hu Chen [a]

[a] Key Laboratory of Western China's Environmental Systems, College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China
[b] Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, United States
[c] Cooperative Institute for Research in Environmental Sciences, University of Colorado and NOAA National Climatic Data Center, Boulder, CO 80305, United States
[d] Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710061, China

A R T I C L E I N F O

Article history:
Received 16 January 2017
Received in revised form
12 October 2017
Accepted 28 October 2017

Keywords:
Paleotemperature reconstructions
Alkenone
Central Asia
Lake Balikun

A B S T R A C T

Numerous studies have demonstrated that there are major differences in the timing of maximum Holocene precipitation between the monsoonal East Asia and westerly dominated Central Asia, but it is unclear if the moisture differences are also associated with corresponding temperature contrasts. Here we present the first alkenone-based paleotemperature reconstructions for the past 21 kyr from Lake Balikun, central Asia. We show, unlike the initiation of Holocene warm conditions at ~11 kyr BP in the monsoon regions, the arid central Asia remained in a glacial-like cold condition prior to 8 kyr BP and experienced abrupt warming of ~9 °C after the collapse of the Laurentide ice sheet. Comparison with pollen and other geochemical data indicates the abrupt warming is closely associated with major increase in the moisture supply to the region. Together, our multiproxy data indicate ~2 thousand years delay of temperature and moisture optimum relative to local summer insolation maximum, suggesting major influence of the Laurentide ice sheet and other high latitude ice sheet forcings on the regional atmospheric circulation. In addition, our data reveal a temperature drop by ~4 °C around 4 kyr BP lasting multiple centuries, coinciding with severe increases in aridity previously reported based on multiproxy data. In contrast, model simulations display a much less pronounced delay in the initiation of Holocene warm conditions, raising unresolved questions about the relative importance of local radiative forcing and high-latitude ice on temperature in this region.

1. Introduction

There have been extensive studies of moisture changes in China and central Asia from LGM to present (e.g., Dykoski et al., 2005; Herzschuh, 2006; Chen et al., 2008; An et al., 2012, 2013; Z. An et al., 2012; Wang and Feng et al., 2013). Broadly speaking, there are two moisture source regimes: southeastern China is dominated by summer monsoon precipitation originating from the tropical Pacific and Indian Oceans, whereas central Asia and northwestern China are dominated by moisture from the Westerlies (Zhou et al., 2009; Liu et al., 2014; Chen et al., 2008). A large amount of paleohydrological data indicate overall drier conditions during the glacial and wetter conditions during the Holocene for both regimes, with the exception of a distinct difference for the timing of Holocene Climate Optimum: the Central Asia region during the middle Holocene 8 - 6 kyr BP (e.g., An et al., 2012; Chen et al., 2008), but the summer monsoon region around 11.5–5 kyr BP (e.g., Z. An et al., 2012; Dykoski et al., 2005). Such difference has been attributed to the influence of the last substantial remnants of northern Hemisphere ice-sheets on the atmospheric circulation (Chen et al., 2008), including the Laurentide ice sheet (LIS) and the Fennoscandian ice sheet (FIS) (Linden et al., 2006; Carlson et al., 2008). Alternatively, some model simulations of the early Holocene indicate that ice sheets had little effect on central Asian aridity, instead decreased winter temperatures over the North Atlantic due to early Holocene orbital forcing had a significant impact on evaporation and atmospheric moisture (Jin et al., 2012).

In contrast to hydrological history, our knowledge of

* Corresponding author.
** Corresponding author. Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, United States.
E-mail addresses: cban@lzu.edu.cn (C.-B. An), Yongsong_Huang@brown.edu (Y. Huang).

https://doi.org/10.1016/j.quascirev.2017.10.036
0277-3791/

temperature variations for the region is much less complete. Pollen data provide a long term estimate of temperature changes for relatively wet regions in southeastern China (e.g., Zhu et al., 2008). Geochemical data from Chinese loess plateau (Peterse et al., 2011; Gao et al., 2012; Jia et al., 2013) and Lake Qinghai (Hou et al., 2016) provide higher resolution reconstructions of temperature changes for the summer monsoon regions. The overall pattern is that the regional temperature responds strongly to summer insolation changes (Gao et al., 2012; Hou et al., 2016), but with major interruption at times of reduced North Atlantic Deepwater (NADW) formation, as well as around 8.2 kyr BP (Hou et al., 2016). However, temperature variations are poorly known for the westerly-dominated central Asia. Regional vegetation is primarily controlled by moisture hence reconstruction of temperature based on pollen induces major uncertainties. Thus, a major scientific question is whether the observed difference in delayed timing of hydrological change during the early Holocene in central Asia can also be found in the temperature record. In modern conditions, cold conditions are generally associated with dry conditions, and therefore, we hypothesize that temperature in the early Holocene may also exhibit delayed warming, coeval with moisture variations.

Here we present a high-resolution alkenone-based paleotemperature reconstruction from Lake Balikun, in central Asia. The central objective is to test the hypothesis that the delayed moisture optimum during the Holocene at Lake Balikun is also associated with delayed temperature optimum in central Asia.

2. Material and methods

2.1. Study area

Lake Balikun (43.60–43.73°N, 92.74–92.84°E, 1570 m a. s. l.) is a closed-basin, hyper-saline lake (salinity 93.8–126.4 g/L), situated in the eastern Tianshan Mountains, western China (Fig. 1; Fig. S1) (Zhao et al., 2014, 2015). Previous study suggested that the Lake Balikun was always a closed basin during the late Quaternary (Ma et al., 2004). The Lake Balikun has an area of 116.0 km^2 within a catchment of approximately 4500 km^2, sandwiched by Balikun Mountains in the south and Moqinwula Mountains in the northeast (Wang and Dou, 1998) (Fig. S1). The prominent mountain peaks in the catchment area have elevations of approximately 3800–4319 m a.s.l. (Fig. S1). The annual precipitation near Lake Balikun ranges from to 120–342 mm, with 54 ± 9 (1σ) % falling in the summer months (June to August), based instrumental data from 1960 to 2008 (Zhao et al., 2015). The lake water is supplied by Dahe River, which originates on the northern slopes of the Balikun Mountains, runs along the steppe from east to west and finally discharges into the Lake Balikun (Fig. S1). Dahe River water derives from both summer rain and spring-melting of snow accumulated during the winter and early spring on Balikun Mountains: the percentage of water from these two sources depends on seasonal distribution of rainfall. Lake Balikun reaches maximum surface area either during the summer at the peak rainy season, or during spring following the major melt water discharge, again depending on shifts in seasonal precipitation patterns. The prevailing wind directions in all seasons are west to east or northwest to southeast (summer monsoon thus does not reach this region). In recent years, permanent glaciers on surrounding mountains have disappeared, hence no longer provide sustained water supply to Dahe River during the warm seasons. The mean annual temperature in the drainage basin is ~1.9 °C (monthly minimum −24.6 °C, maximum 21.3 °C). A cool and dry season occurs in this region during the boreal winter when the Siberian High establishes, giving rise to a strong anticyclone over Eurasia inland; conversely, a relatively warm and wet season prevails during the summer months when the Siberian High diminishes and the Westerlies climate dominates (Fig. S2). Thus, Lake Balikun is an ideal site to study the variability of Westerlies and climate change in the arid central Asia.

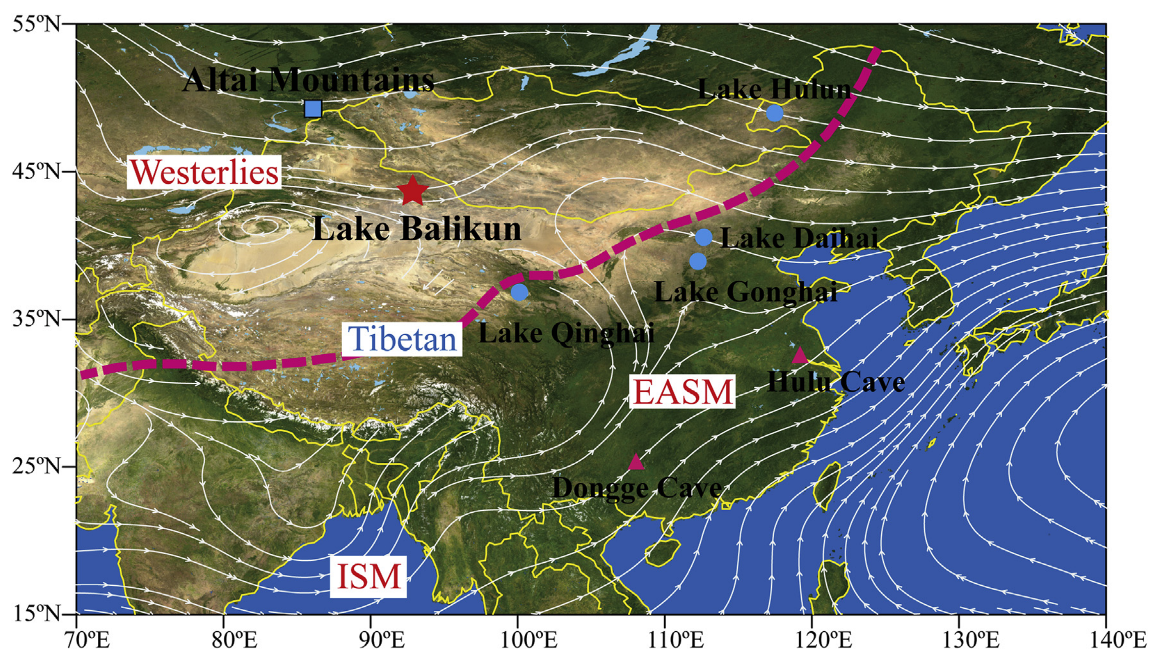

Fig. 1. Summer (June-July-August, JJA) mean 700 hPa streamline based on NCEP/NCAR Reanalysis during 1971–2000. Red star indicates the location of Lake Balikun. 'EASM', 'ISM', and 'Westerlies' denote the regions mainly influenced by the East Asian Summer Monsoon, the Indian Summer Monsoon, and the Westerlies, respectively. Triangles indicate the caves mentioned in the text, Dongge cave (25°17′ N, 108°5′ E) and Hulu cave (32°30′ N, 119°10′ E). Blue dots indicate the lakes mentioned in the text, Lake Qinghai (36°32′-37°15′ N, 99°36′-100°47′ E); Lake Gonghai (38°54′ N, 112°14′ E); Lake Daihai (40°29′-40°37′ N, 112°33′-112°46′ E); Lake Hulun (49°7.6′ N, 117°30.4′ E). Blue square indicates ice cores (49°48′ N, 86°33′ E) from the Altai Mountains. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)