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Holocene climatic fluctuations and periodic changes in the Asian southwest monsoon region

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ABSTRACT

Climatic changes in the Asian southwest monsoon (ASWM) during the Holocene have become a topic of recent studies. It is important to understand the patterns and causes of Holocene climatic changes and their relationship with global changes. Based on the climate proxies and wavelet analysis of Lugu Lake in the ASWM region, the climatic fluctuations and periodic changes in the ASWM region during the Holocene have been reconstructed with a high-precision chronology. The results indicate the intensification of ASWM began to increase with Northern Hemisphere low-latitude solar insolation (LSI) and solar activity during the early Holocene, and gradually decreased during the late Holocene, exhibiting an apparent synchrony with numerous records of ASWM region. Meanwhile, an apparent 1000-a quasi-periodic signal is present in the environment proxies, and it demonstrates that the environmental change in the ASWM region has been driven mainly by LSI and solar activity.

1. Introduction

The Asian southwest monsoon (ASWM) is important for socio-economic and cultural development in the Asian region, and the seasonal rainfall affected almost one-third of the world's population (Webster et al., 1998; WCRP, 2009; Li and Morrill, 2013; An et al., 2015). It not only controls the precipitation within southwest China, but may also affect the eastern Asia (Chen et al., 2014, 2015; Huang et al., 2016). However, the previous climate change studies are divergent views involving the characteristics of the ASWM during the Holocene (Fleitmann et al., 2003; Thamban et al., 2007). For example, based on the variation of solar insolation in the Northern Hemisphere and global ice volume reduction (Bond et al., 1997; Cook et al., 2013), some results have suggested that the ASWM was significantly enhanced from the Late Glacial period to the early Holocene, and reached its climatic optimum during the Middle Holocene (An et al., 2011; Cui et al., 2015), and it was weakening gradually during the mid-to-late Holocene (Hodell et al., 1999), compared to the aridification (Neff et al., 2001; Fleitmann et al., 2003; Cook et al., 2010; Ponton et al., 2012) and warm-dry climate (Hodell et al., 1999; Morrill et al., 2006; Zhang et al., 2014). However, some studies discovered that the pattern of Indian summer monsoon (ISM) evolution was similar to the East Asian summer monsoon (EASM) during the Holocene (Song et al., 2012). Therefore, well-dated records of ASWM proxies and high-accurate chronology are necessary to study the dynamic mechanism and the evolution of the ASWM during the Holocene.

Yunnan Plateau is located on the southeast margin of the Tibetan Plateau (TP), and it is the typical the ASWM region (Zhang et al., 2015). The reconstruction of the climate and environmental change in ASWM region covering the Holocene becomes sensitive because of the large number of tectonic fault lakes and the most abundant biodiversity (Zhang et al., 2015).

Here, based on eight radiocarbon datings of terrestrial plant macrofossils and charcoal, we present the high-resolution climate proxies and wavelet analysis of lacustrine deposits in Lugu Lake, and mainly aim to investigate the evolution history of the ASWM and assess the possible dynamic mechanism during the Holocene.

2. Study area

Lugu Lake (27°40′ ~ 27°45′ N, 100°45′ ~ 100°50′ E) is located in the northwest Yunnan Plateau (Fig. 1). It is a semi-closed deep lake situated 2692 m above sea level, and has a water surface area of 57.7 km^2 and a catchment area of 216 km^2 (Wu et al., 2016). Its mean water depth is

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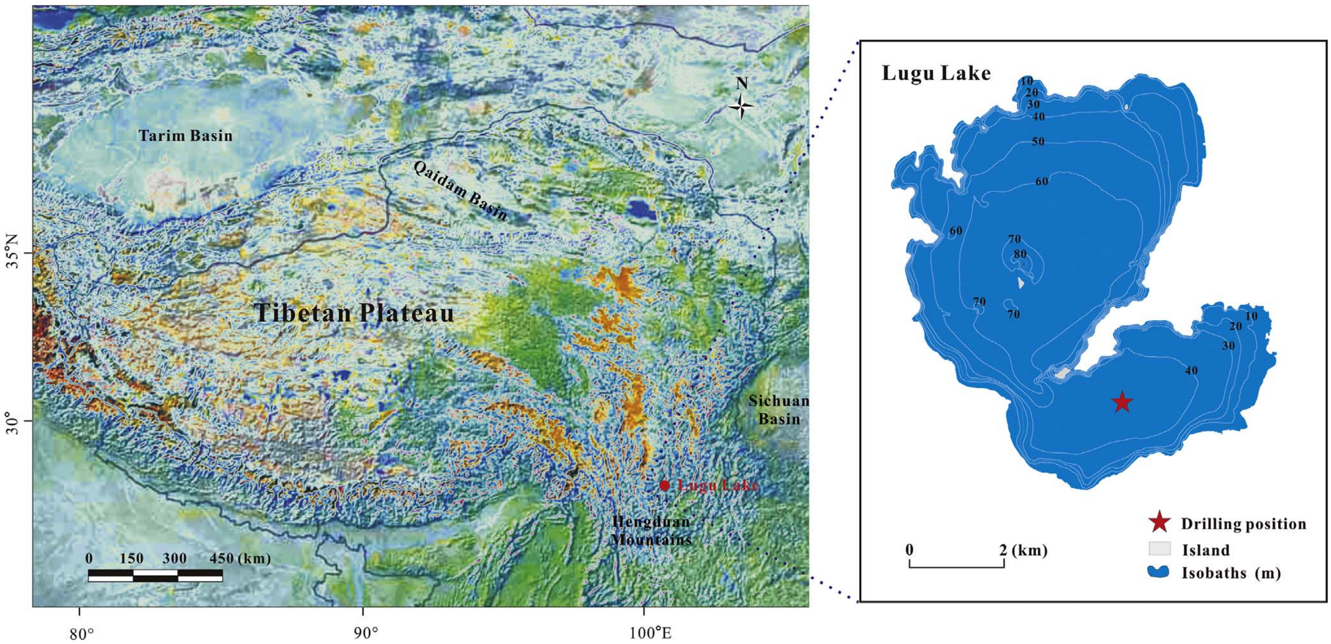

Fig. 1. The location of Lugu Lake cores (The data come from http://srtm.csi.cgiar.org for open-source (Jarvis et al., 2008). The figure was generated using QGIS software (QGIS Development Team, 2013), and is therefore for illustrative purposes only).

approximately 40.3 m, mean annual temperature is 12.8 °C, and the mean annual precipitation is approximately 785 mm, with more than 85% falling between June and October (Wen et al., 2016). The lake catchment has a significant vertical differentiation of soil and vegetation (Xu et al., 2014a). The previous studies showed that the sediments contained abundant plant fossils and charcoal (Zheng et al., 2014).

3. Material and methods

3.1. Sampling and experimental analysis

In 2014, a sediment core in length of 880 cm was recovered by using a piston corer from the southern part of the deep basin of Lugu Lake in water 44.5 m deep (27°40′49″ N, 100°48′00″ E). Then the core was sampled in the field at 1.0-cm intervals, and the subsamples were sealed in plastic bags for transport to the laboratory. The stable isotope ratio analysis ($\delta^{13}C$ and $\delta^{15}N$) and measurements of total organic carbon (TOC) and total nitrogen (TN) of the samples were carried out at he Key Laboratory of Plateau Geographic Processes and Environment Change of Yunnan Province using a Finnigan MAT253 mass spectrometer. Isotope ratios are reported in δ-notation, where $\delta = (R_s/R_{st} - 1) \times 1000$. R_s and R_{st} are the isotope ratios of the sample and the standard (PDB for carbon, AIR for nitrogen), respectively. The analytical precision was ± 0.1% for $\delta^{13}C$ and $\delta^{15}N$, 0.1 mg/g for TOC and 0.05 mg/g for TN, respectively. The AMS ^{14}C dates were measured at the AMS Laboratory of Beijing University, and the dates were calibrated to calendar years by the latest calibration program (Reimer et al., 2013).

3.2. Wavelet spectrum analysis

For the multi-resolution and mathematical microscope properties, wavelet transform is often used to study climatic fluctuations and periodic changes as a powerful mathematical tool (Dykoski et al., 2005; Debret et al., 2009). A sequence of the climate proxies of Lugu Lake in equal time intervals was obtained via cubic spline interpolation. Meanwhile, the wavelet coefficients of climate proxies were obtained by the Morlet continuous wavelet transform (CWT). The Morlet wavelet function is expressed as (Mallat and Hwang, 1992; Blaauw and Christen, 2011):

$$\varphi(t) = \pi^{-\frac{1}{4}}e^{-\frac{t^2}{2}}e^{i\omega t} \quad (1)$$

Its daughter wavelet is formulated as

$$\varphi_{a,b}(t) = \frac{1}{\sqrt{a}}\varphi\left(\frac{t-b}{a}\right) \quad (2)$$

In both (1) and (2), t is time of the index age of the sample; a and b are the scale factor and displacement factor, respectively; and φ means dimensionless frequency (Torrence and Compo, 1998).

4. Results

4.1. Age model and chronology

Based on the previous research of the core (Zheng et al., 2014), the age at 3 cm is 1950 AD which was set as the beginning of the AMS age. Based on the AMS ^{14}C dates of eight plant macrofossil samples (Table 1) and the Bayesian model of age-depth, the ages extended back to ~12.8 cal. ka BP at 420 cm of the Lugu Lake core (Fig. 2). The sedimentation rate of the lower layers (411–301 cm) is approximately 0.259 mm/a; it is approximately 0.370 mm/a (301–0 cm) in the upper layer, corresponding with that of the lakes in Yunnan Plateau (Chen et al., 2014; Zhang et al., 2014).

4.2. Climate proxies

The climate proxies of Lugu Lake indicate that three main zones can be distinguished, which can be interpreted as correspondences into three climate regimes (Fig. 3). Values of TOC vary between 6.38% and 13.80% with a mean value of 9.74% (Fig. 3a), and gradually increase to a peak value from 324 cm to 183 cm (10.02–4.75 cal. ka BP). The obvious fluctuations and the lowest value in 90 cm to the top (2.12–0 cal. ka BP) of the sediment core. These indicate a decrease biomass and environmental change in the lake catchment. The low TN content, with an average of 0.41% (Fig. 3b), is well correlated with TOC (R = 0.927). The C/N ratio varied from 13.36 to 21.78 (Fig. 3c), which suggested that sedimentary organic matter primarily originates from terrestrial plant. The values of $\delta^{13}C$ vary from −28.49‰ to −26.74‰, with an