Quaternary Science Reviews 195 (2018) 122–132

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

High resolution monsoon precipitation changes on southeastern Tibetan Plateau over the past 2300 years

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ARTICLE INFO

Article history:
Received 2 April 2018
Received in revised form
10 July 2018
Accepted 13 July 2018

Keywords:
Monsoon precipitation
Tibetan plateau
Southwestern China
Spatial pattern
Stalagmite

ABSTRACT

Climate changes on Southeastern Tibetan Plateau have important impacts on social and economic development, as well as the ecosystem of southwestern China and Indo-China Peninsula. Here, we collected two stalagmites from Shenqi (Miraculous) cave in southern Sichuan, China. The stalagmite $\delta^{18}O$ record shows good coherence with local instrumental rainfall record, as well as tree ring- and pollen-based moisture reconstructions from southeastern Tibetan Plateau during overlapped time periods. As a result, we reconstructed high-resolution (~4.9 yrs) monsoon precipitation variations on southeastern Tibetan Plateau over the past 2300 years by using the combined stalagmite $\delta^{18}O$ record.

The result reveals an overall decreasing precipitation trend, with two most notable wet periods occurred in 60–280 AD and 370–510 AD. The most remarkably dry period is the recent 200 years. Some decadal scale wet and dry intervals were also identified. The abnormal drought during 1160–1245 AD might have accelerated Dali kingdom's demise at 1253 AD. Power spectrum analysis indicated significant 373-, 187-, 22-, 12- and 11- yr cycles in our stalagmite record, suggesting the impact of solar activity. Increased monsoon precipitation on southeastern TP was observed in solar activity minima during the last millennium. We further synthesized an integrated precipitation record for southwestern China and discussed spatial patterns of precipitation over China during the last two millennia. The comparisons confirm a "dry southern and wet northern" pattern in monsoonal China during the Medieval Warm Period and a "wet southern and dry northern" pattern during the Little Ice Age and Dark Age Cold Period. Solar activity, the strength of westerly jet and summer monsoon, as well as the SST of tropical Indo-Pacific might play important roles on the rainfall spatial patterns over monsoonal China during the last 2000 years.

1. Introduction

Southeastern Tibetan Plateau (TP) is the cradle and/or upper reaches of many large rivers in Asia, including Yangtze River, Lancang-Mekong River, Nu-Salween River and Irrawaddy River. This region is also the refuge of many animals and plants since Pleistocene with a high-biodiversity ecosystem. The runoff changes of these rivers have important impacts on the social and economic development as well as the ecosystem of southwestern China and Indo-China Peninsula. Large inter-annual variations of the runoff of these rivers in recent decades have drawn many attentions of the general public and governments (Räsänen and Kummu, 2013). Runoff change is part of the hydrological cycle and has a close relationship with climate change (You and He, 2005; You et al., 2005). Understanding the variability and mechanisms of historical monsoon precipitation in southeastern TP on centennial-to decadal-timescales especially during historical warm periods is important for evaluating future trends of runoff changes of these

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https://doi.org/10.1016/j.quascirev.2018.07.021
0277-3791/

large rivers.

Previous studies on lacustrine sediments provided a good understanding of Holocene climate changes in this region (Chen et al., 2005, 2014a, 2014b; Shen et al., 2006; Sheng et al., 2015; Xiao et al., 2014; Xu et al., 2015a, 2015b). They suggested that temperature and precipitation gradually increased during 11510-10000 yr BP (BP stands for “Before Present” where the “Present” is defined as the year 1950 AD) and climate became warmer and wetter during 10000–6100 yr BP. Warm and wet climate sustained in southwestern China during 6100–3410 yr BP. Temperature and precipitation started to decrease after 3410 yr BP (Chen et al., 2014b; Xiao et al., 2014). Millennial scale droughts in this region during early and mid-Holocene were suggested to be influenced by weak solar activities (Xu et al., 2015a). Recently, a generally dry Medieval Warm Period (MWP, 950–1300 AD) and wet Little Ice Age (LIA, 1400–1850 AD) (Lamb, 2002) were observed in this region (Sheng et al., 2015; Xu et al., 2015b). However, existing lacustrine records in this region cannot reflect the characteristics of multidecadal-to decadal-timescale variability of monsoon precipitation due to their low resolutions and relatively large dating errors. Existing tree ring records from southeastern TP (An et al., 2014; Fan et al., 2008; Liu et al., 2012, 2013, 2014a; Wernicke et al., 2015) are less than 800 years long and unable to reveal variations of monsoon precipitation in the historical warm periods such as MWP and Roman Warm Period (RWP, centered in 100 BC-100 AD) (Lamb, 2002).

Here, we collected two stalagmites from Shenqi (Miraculous) cave in southern Sichuan, China, and reconstructed high-resolution monsoon precipitation variations in southeastern TP over the past 2300 years by using stalagmite $\delta^{18}O$ records. We further synthesized an integrated precipitation record for southwestern China, and discussed spatial patterns and driving forces of precipitation over China during the last two millennia.

2. Cave and regional climatology

Shenqi cave (28°56 ′N, 103°06 ′E, 1407 m above sea level) is located 37 km southwest of Ebian county, Sichuan, China on the southeast margin of TP (Fig. 1). The cave, formed in Triassic dolomitic limestone, has a small entrance of $3 \times 4\,m^2$, and its total length exceeds 400 m. An underground river was developed in the cave along with the main passage (Fig. 2). Monitoring results during Sep. 2014 and Oct. 2016 show stable temperature and relative

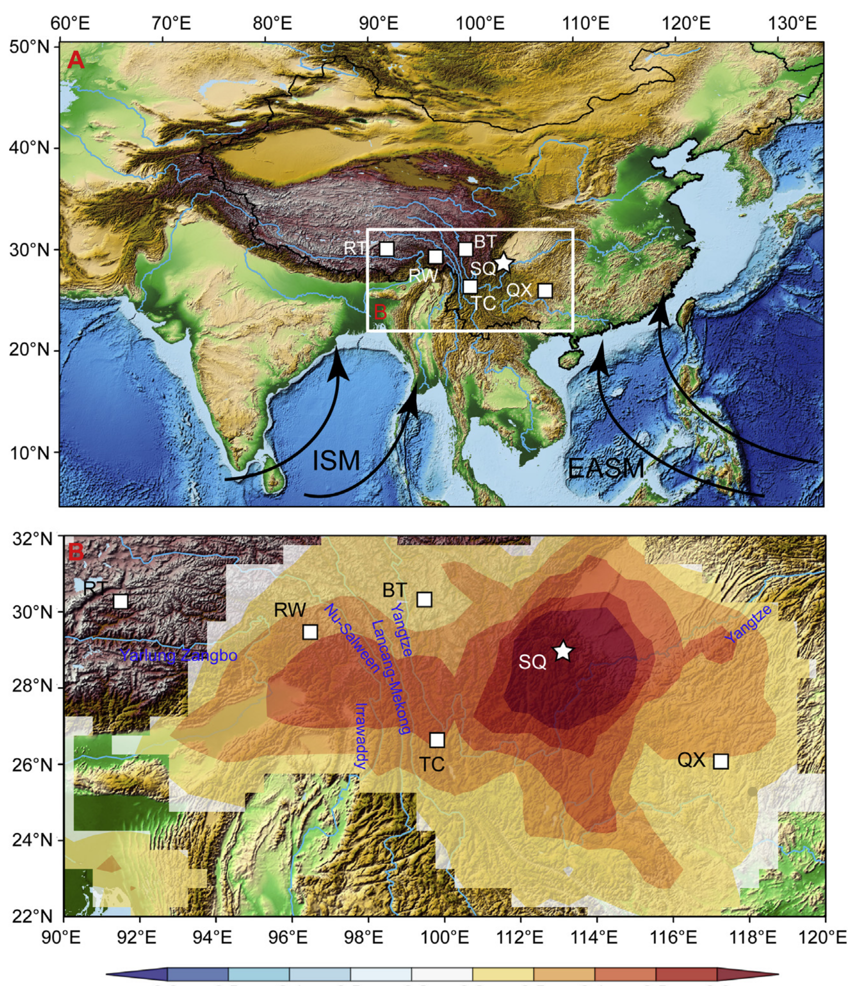

Fig. 1. Location of Shenqi cave. The upper panel A is an overview topographic map showing the study region. Black arrows denote directions of the East Asian summer monsoon (EASM) and Indian summer monsoon (ISM). The lower panel B is an enlarged map showing the location of Shenqi cave on the southeast margin of TP. Tree ring sites of Ranwu (RW, Liu et al., 2013), Batang (BT, An et al., 2014), Reting (RT, Grießinger et al., 2011), and Tiancai lake (TC, Xiao et al., 2014), as well as Qixing cave (QX, Ma et al., 2015) are also shown. Spatial correlation between the CRU gridded annual precipitation around the Shenqi cave area (28–29° N, 103–103.5° E) and the CRU TS3.10.01 precipitation grid datasets during 1960–2009 AD are shown in panel B. The scale on the bottom shows the correlation coefficients represented by different colors. It shows that the annual precipitation changed synchronously over southwestern China, especially on southeastern TP. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)