Quaternary Science Reviews 122 (2015) 250–257

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

A high-resolved record of the Asian Summer Monsoon from Dongge Cave, China for the past 1200 years

Kan Zhao [a], Yongjin Wang [a, *], R. Lawrence Edwards [b], Hai Cheng [b, c], Dianbing Liu [a], Xinggong Kong [a]

[a] College of Geography Science, Nanjing Normal University, Nanjing 210097, China
[b] Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, USA
[c] Institute of Global Environmental Change, Xi'an Jiaotong University, Xi'an, 710049, China

ARTICLE INFO

Article history:
Received 14 August 2014
Received in revised form
6 May 2015
Accepted 29 May 2015
Available online 16 June 2015

Keywords:
Asian Summer Monsoon
Past millennium
Stalagmite
$\delta^{18}O$
Dongge Cave
China

ABSTRACT

Two annually-laminated and ^{230}Th-dated stalagmite oxygen isotope ($\delta^{18}O$) records from Dongge Cave, China, provided a high-resolution Asian Summer Monsoon (ASM) history for the past 1200 years. A close similarity between annual band thickness and stable isotope analyses ($\delta^{13}C$ and $\delta^{18}O$) suggests the calcite $\delta^{18}O$ is most likely a proxy associated with ASM precipitation. The two duplicated stalagmite $\delta^{18}O$ records show that the ASM varies at a periodicity of ~220 years, concordant with a dominant cycle of solar activity. A period of strong ASM activity occurred during the Spörer Minimum (1450–1550 A.D.), followed by a striking drop circa 1580 A.D., potentially consistent with the social unrest in the final decades of China's Ming Dynasty (1368–1644 A.D.). Centennial-scale changes in ASM precipitation over the last millennium match well with changes in tropical Atlantic sea surface temperatures (SSTs) and South American summer monsoon precipitation. Our findings suggest that variations in low-latitude monsoon precipitation are probably driven by shifts in the mean position of the intertropical convergence zone (ITCZ), which is further mediated by solar activity and tropical SSTs.

1. Introduction

The Asian Summer Monsoon (ASM) is of great importance in transporting moisture to the most-populated parts of the Asian continent. Monsoon rainfall has been reported to be strikingly unstable over the past millennium (Zhang et al., 2008; Cook et al., 2010; Sinha et al., 2011). Episodic and widespread recurrences of monsoon megadroughts continued throughout the last millennium, and these appear to have played a major role in shaping significant regional societal changes. However, the causes of decadal-centennial ASM variations remain less certain. Three forcing mechanisms have been suggested as possible factors: solar variability (Agnihotri et al., 2002; Fleitmann et al., 2003; Zhang et al., 2008; Sachs et al., 2009; Steinhilber et al., 2012), North Atlantic climate change (Wang et al., 2005; Zhang and Delworth, 2006; Goswami et al., 2006; Feng and Hu, 2008; Linderholm et al., 2011) and the El Niño-Southern Oscillation (ENSO) (Wang et al., 2000; Ailikun and Yasunari, 2001; Wang and An, 2002; Ashok et al., 2004; Goswami and Xavier, 2005). Due to minor changes (0.1–0.26%) in solar irradiance (Rind, 2002), the North Atlantic hydrographic changes and ENSO potentially provide an additional mechanism for amplifying solar signals (Bond et al., 2001; Emile-Geay et al., 2007).

Recent studies have suggested a close link between solar variability, North Atlantic climate change (Gray et al., 2010; Scaife et al., 2013) and ENSO (Emile-Geay et al., 2013). Changes in the deep water formation in the North Atlantic were believed to provide a mechanism for amplifying solar signals and transmitting them globally (Bond et al., 2001). This, in turn, affected the latitudinal position of the ITCZ (Chiang and Bitz, 2005; Zhang and Delworth, 2005), resulting in variations in low-latitude monsoon precipitation (Haug et al., 2001; Yancheva et al., 2007; Sachs et al., 2009). Alternatively, ENSO may plausibly have acted as a mediator between the Sun and the Earth's climate (Mann et al., 2005; Asmerom et al., 2007; Emile-Geay et al., 2007, 2013). For instance, a persistent positive North Atlantic Oscillation (NAO) during the Medieval Climate Anomaly (MCA) (Trouet et al., 2009) appears to be associated with prevailing La Niña-like conditions, possibly initiated by

---

* Corresponding author.
E-mail addresses: zhaokan19821026@163.com (K. Zhao), yjwang@njnu.edu.cn (Y. Wang), edwar001@umn.edu (R.L. Edwards), cheng021@umn.edu (H. Cheng), ldb9921@163.com (D. Liu), Kongxinggong@njnu.edu.cn (X. Kong).

http://dx.doi.org/10.1016/j.quascirev.2015.05.030

enhanced solar irradiance (Mann et al., 2005, 2009). Furthermore, atmospheric teleconnections related to the NAO and/or ENSO are probably complementary in modulating monsoon behavior (Goswami et al., 2006). However, it remains unclear to what extent these forcing factors are able to dominate ASM variability, especially on decadal to centennial timescales.

Here, we present a high-resolution ASM record for the past 1200 years from two precisely-dated laminated stalagmites from Dongge Cave. This record allows us to: (1) detect the nature of decadal-centennial ASM oscillations; and (2) explore possible mechanisms driving decadal-centennial ASM variability.

2. Materials and methods

Dongge Cave (25°17′N, 108°05′E; 680 m above sea level) is located in Guizhou Province, southwestern China (Fig. 1). Densely-forested vegetation at the cave and in its surrounding area consists primarily of evergreen broadleaved plants. Relative humidity inside the cave is close to 100%. Modern climate information from this area has previously been reported by Yuan et al. (2004) and Dykoski et al. (2005). Current mean annual air temperature in the cave is 15.6 °C. Mean annual precipitation near Dongge Cave is 1753 mm. This area is strongly affected by the ASM. Most of the annual rainfall (80%) occurs during the rainy season (May–October) when the convective monsoon rainfall prevails, with much less precipitation (20%) occurring during the dry season (November–April).

Two stalagmites were collected (they had stopped growing before collection) about 150 m from the cave entrance. Samples DX1 and DX2 are 174 mm and 127 mm in length, respectively. Each of the stalagmites has a diameter that ranges between 55 mm and 90 mm. The samples were halved along their growth axes, and then polished. A man-made hiatus occurred at a depth of 83.5 mm from the top of DX1; a growth hiatus was identified at 25.3 mm from the top of DX2. In this study, we focus only on the upper portion of the two samples. In the continuously-growing sections, regular laminations can be observed under the microscope (Fig. S1). The microscopic features of the lamina resemble those from several other caves in the monsoonal regions of China (Tan et al., 2006; Wu et al., 2006). Band counting was performed under an Olympus optical microscope following the procedures described in Tan et al. (2003). Within statistical error, three duplicate counts along different transects yielded a total of 1139 bands (777 ± 30 for DX1 and 362 ± 10 for DX2).

Eighteen sub-samples (fifteen for DX1 and three for DX2) were collected for U–Th dating. Procedures for chemical separation and purification of uranium and thorium are similar to those described in Edwards et al. (1987) and Cheng et al. (2000). ^{230}Th dating was performed at the Minnesota Isotope Laboratory on a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS, Thermo-Finnigan Neptune). A total of 1738 sub-samples (1156 for DX1 and 582 for DX2) were collected by knife shaving for stable isotope analysis. The analyses were performed in the Isotope Laboratory of Nanjing Normal University on a Finnigan MAT-253 mass spectrometer. Precision of stable isotope values is 0.06‰, at the 1-sigma level. The average sampling interval for these stable isotope analyses is ~1 year.

3. Results

3.1. Chronology

Isotope chronology was based on both U–Th dating and annual growth band count (Fig. 2). The ^{230}Th dating results (Table S1) show that sub-samples have high uranium concentrations (1.6–3 ppm) and low initial thorium contents (40–600 ppt), leading to small dating errors (ranging from ± 7–18 years). Nonetheless, correction for the effect of ^{230}Th incorporated at the time of deposition is important (Li et al., 1989; Richards and Dorale, 2003; Hellstrom, 2006), especially for young stalagmites. Any initial ^{230}Th is always accompanied by a much larger amount of ^{232}Th. Therefore, ^{232}Th was routinely monitored during analysis, and samples containing less than an acceptable threshold of ^{230}Th relative to ^{232}Th were objectively identified and rejected. In this study, samples with measured ^{230}Th/^{232}Th activity ratio >300 have generally been regarded as reliable, i.e. the detrital Th is negligible for ^{230}Th corrections. We can therefore identify seven reliable ^{230}Th ages (three in the band-counting interval) for stalagmite DX1, and none for DX2 (Table S1).

Annual bands, as observed in the upper sections of the two samples (0–58.2 mm for DX1 and 0–25.3 mm for DX2), can be used to establish band-counting timescales. The two independent band-counting timescales were tested by comparing their $\delta^{18}O$ profiles (Fig. S2). Visual inspection shows that variations in the $\delta^{18}O$ of DX1 and DX2 are generally similar, particularly with regard to decadal-scale oscillations and one distinct heavy $\delta^{18}O$ excursion. The correlation coefficient between them reaches 0.53 ($n = 351$, $p < 0.001$). In detail, the structure and amplitude of several equivalent

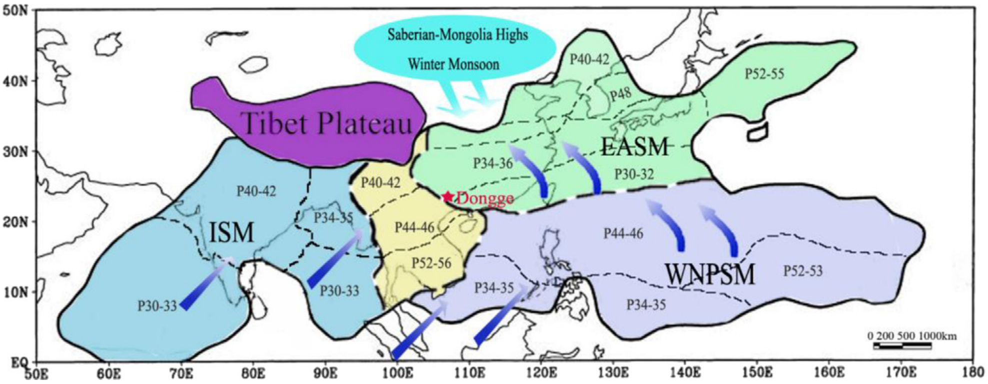

Fig. 1. The Asian monsoon region and cave location. Red star indicates Dongge Cave (25°17′N, 108°05′E) in southwestern China. Blue arrows show moisture transport directions in summer; cyan arrows indicate prevailing winter monsoon wind directions. Based on rainy season characteristics, the Asian-Pacific monsoon is demarcated into three components: the Indian summer monsoon (ISM), the western North Pacific summer monsoon (WNPSM), and the East Asian Summer Monsoon (EASM). P with numbers indicates the timing of monsoon rainfall peak. There are 73 pentads (5-day periods) in a 365-day year. Typically, P1 refers to the first pentad after the start of the year (Wang and Lin, 2002). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)