Journal of Hydrology 566 (2018) 164–174

Contents lists available at ScienceDirect

Journal of Hydrology

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

Research papers

Potential ENSO effects on the oxygen isotope composition of modern speleothems: Observations from Jiguan Cave, central China

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ARTICLE INFO

This manuscript was handled by Huaming Guo, Editor-in-Chief, with the assistance of Pedro J. J Depetris, Associate Editor

Keywords:
Oxygen isotope
Precipitation
Karst drip water
Modern speleothems
El Niño Southern Oscillation
Jiguan Cave
Central China

ABSTRACT

Despite of the fast development of speleothem records, oxygen isotope ($\delta^{18}O$), the main paleoclimatic proxy, remains complicated in climatic interpretation. Continuous cave monitoring is essential for understanding the response of stalagmite oxygen isotope to East Asian Summer Monsoon moisture transportation. We introduce a 7 years (2010–2016) study on oxygen isotope of atmospheric precipitation, cave drips and modern speleothems at Jiguan Cave, central China, located Chinese north–south divide where is sensitive to Asian Monsoon. The monitoring covered a whole ENSO (El Niño Southern Oscillation) cycle, from El Niño in 2010 to La Niña in 2011 and recovered another El Niño in 2015. The precipitation $\delta^{18}O$ shows obvious seasonality (negative in summer and positive in winter), but air temperature and rainfall amount are not primary controlling factors. The interannual $\delta^{18}O$ of precipitation corresponds with ENSO variability, which means $\delta^{18}O$ value is positive during El Niño event and vice versa. We used HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model to simulate the moisture transportation for rainy season in El Niño and La Niña years, and found the Pacific contributed over 50% moisture in El Niño years and the Indian Ocean was the predominant oceanic source in La Niña year. There is no seasonality in drips $\delta^{18}O$ value, while the response to ENSO variability is evident on interannual scale. The stable negative $\delta^{18}O$ of drips compared with precipitation indicate there is a threshold for infiltration, suggesting cave drips are recharged by summer heavy precipitation with light $\delta^{18}O$ value, but it's the mixture of latest and former rainy precipitation that recharge drips in drought, which has been verified by simple infiltration model. We found the modern speleothems were precipitated under nonequilibrium fractionation during drought years, nevertheless, they can record the El Niño related $\delta^{18}O$ positive anomaly. Overall, the modern speleothems can receive the precipitation $\delta^{18}O$ signal transferred by drips, and our study offers significance for verification of Asian Summer Monsoon driving force and interpretation of stalagmite $\delta^{18}O$.

1. Introduction

Stalagmite, the vital archive for paleoclimate reconstruction, has developed fast recently due to its series of advantages, such as precise dating, widely distribution, continuous precipitation, copious proxies and little external disturbance (e.g., Banner et al., 2007; Cai et al., 2008, 2010; Cheng et al., 2009, 2016; Shopov et al., 2004; Tan et al., 2015; Wang et al., 2001, 2017; Yuan et al., 2004; Zhu et al., 2017). Nevertheless, as the most important proxy, the interpretation of $\delta^{18}O$ remains in argument. Previous studies attributed its controlling factors to rainfall amount or air temperature. For example, Fleitmann et al. (2004) found there was significant anticorrelation between stalagmite $\delta^{18}O$ and bands thickness, which reflected the precipitation variation. Bar-Matthews et al. (2003) revealed the most negative in stalagmite $\delta^{18}O$ from north and central Israel was synchronic with the heaviest rainfall in east Mediterranean. The air temperature was introduced to explain the stalagmite $\delta^{18}O$ variation in Ireland and Austria (e.g., Mangini et al., 2005; McDermott et al., 1999), and supported by the contemporary increasing growth rate.

In general, the stalagmite $\delta^{18}O$ is usually regarded as the East Asian Monsoon signal in China (e.g., Cai et al., 2010; Cheng et al., 2009; Dayem et al., 2010; Hu et al., 2008; Maher, 2008; Yuan et al., 2004). Wang et al. (2001) suggested it was controlled by the ratio between summer and winter precipitation, and Hu et al. (2008) emphasized the

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https://doi.org/10.1016/j.jhydrol.2018.09.015
Received 27 February 2018; Received in revised form 1 August 2018; Accepted 8 September 2018
Available online 10 September 2018

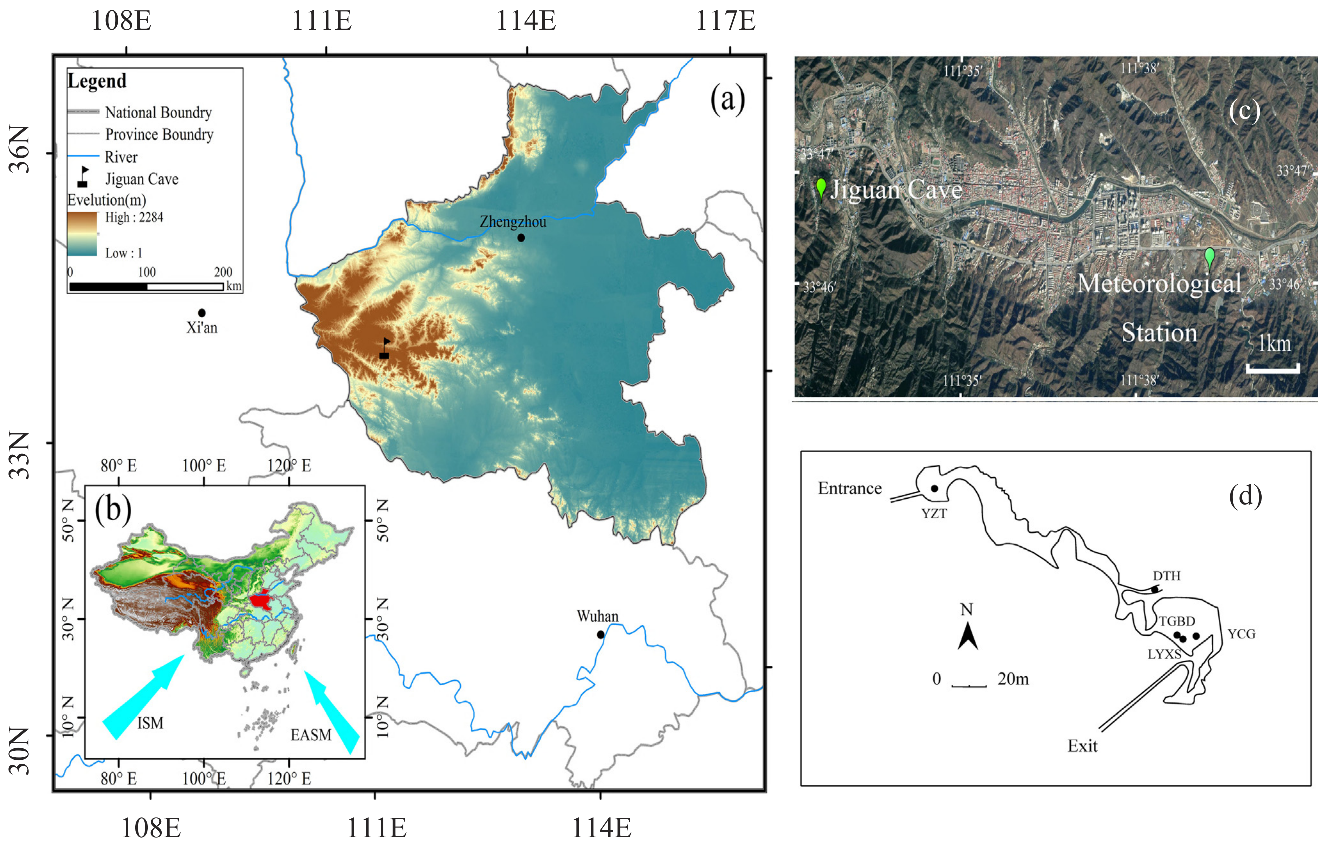

Fig. 1. (a) Location of study site, flag is Jiguan Cave and black dots are the cities included in GNIP (global network of isotopes in precipitation) and referenced in this article, (b) the background of study area and two main monsoon systems influencing this region (ISM: Indian Summer Monsoon, EASM: East Asian Summer Monsoon). (c) Google earth map of Luanchuan County. Jiguan Cave and meteorological station, indicated by green marks. (d) Schematic map of Jiguan Cave. The sampling sites are marked by black dots. YZT (Yu Zhu Tan) and YCG (Yao Chi Gong) are pools, LYXS (Li Yu Xi Shui) and TGBD (Tian Gong Bing Deng) are drips, DTH (Dong Tian He) is underground river in the cave. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

rainfall amount effect. Some researches, however, preferred the change of moisture source rather than amount effect during Holocene in China (e.g., Maher, 2008; Maher and Thompson, 2012). Such conclusion is partly supported by Clemens et al. (2010) and Dayem et al. (2010) who suggested the change of moisture source and upstream rainout process should be taken into consideration.

Cave monitoring is an effective method to accurately understand the speleothem $\delta^{18}O$ significance, and such study has been implemented as early as 1980s (Yonge et al., 1985). Treble et al. (2005) disclosed the evident anticorrelation between precipitation $\delta^{18}O$ and rainfall amount at Moondyne Cave, SW Australia, likely indicating the inaccurate interpretation of stalagmite $\delta^{18}O$ as regulated by temperature. Given the evenly distributed rainfall throughout the year, the seasonality of precipitation $\delta^{18}O$ was attributed to the seasonal change in moisture source at Gunung Mulu and Gunung Buda National Park (Cobb et al., 2007). Furthermore, because of homogenization in the bedrock, cave drips generally exhibit more smooth $\delta^{18}O$ pattern than precipitation, suggesting mixture before infiltrating into cave (eg., Bar-Matthews et al., 2003; Genty et al., 2014; Mischel et al., 2015; Moerman et al., 2014; Vaks et al., 2003). Hence, the stable drips $\delta^{18}O$ are commonly regarded as the mean annual amount weighted precipitation $\delta^{18}O$ for local region (eg., Williams and Fowler, 2002; Yonge et al., 1985), but due to evaporation happened in epikarst or rapid infiltration, drips $\delta^{18}O$ can still reflect apparent variation (eg., Bar-Matthews et al., 1996; Cruz et al., 2005; Denniston et al., 1999; Van Rampelbergh et al., 2013).

Cave monitoring has been widely carried out in south China. The good correlation between $\delta^{18}O$ of precipitation and drips and meteorological parameters (air temperature and rainfall amount) suggests speleothem $\delta^{18}O$ records monsoon variation (Li et al., 2000). Li et al. (2011) found the drips $\delta^{18}O$ in Furong Cave showed stable value with no evident rate change, which was attributed to the mixture of atmospheric precipitation. The positive correlation between drip $\delta^{18}O$ and drip rate was observed at Liangfeng Cave (Luo et al., 2014). And the homogenization effect can be demonstrated by the decreasing $\delta^{18}O$ amplitude of precipitation, soil water and drips (Luo et al., 2013). Duan et al. (2016) compiled 8 long term monitoring caves in China, and found anti temperature effect was observed in 7 caves and the amount effect was feeble. The precipitation $\delta^{18}O$ cannot be simply contributed to temperature or amount effect because of various moisture sources.

As discussed above, current interpretation of speleothem $\delta^{18}O$ basically focuses on amount effect (eg., Bar-Matthews et al., 2003; Fleitmann et al., 2004; Hu et al., 2008), temperature effect (eg., Feng et al., 2014; Mangini et al., 2005), monsoon intensity (eg., Cheng et al., 2016; Wang et al., 2005; Yuan et al., 2004), and moisture source change (eg., Cobb et al., 2007; Dayem et al., 2010; Maher, 2008; Maher and Thompson, 2012). Actually, the parallel speleothem $\delta^{18}O$ variation in Chinese monsoon region on different time scales (Liu et al., 2015) potentially suggests controlled by same circulation pattern. Dayem et al. (2010) found the spatial distance of contemporary speleothems with parallel $\delta^{18}O$ variation was far than 500 km, which was the critical distance for areas share similar meteorological condition. To explain this phenomenon, Tan (2014, 2016) proposed circulation effect, which suggested West Pacific Subtropical High (WPSH) shifted more westwards during El Niño events, thus drove more proximal Pacific moisture to East Asia, and the shorter Rayleigh distillation distance made the ultimate precipitation with positive $\delta^{18}O$. During La Niña events,