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The transfer of seasonal isotopic variability between precipitation and drip water at eight caves in the monsoon regions of China

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Abstract

This study presents new stable isotope data for precipitation ($\delta^{18}O_p$) and drip water ($\delta^{18}O_d$) from eight cave sites in the monsoon regions of China (MRC), with monthly to bi-monthly sampling intervals from May-2011 to April-2014, to investigate the regional-scale climate forcing on $\delta^{18}O_p$ and how the isotopic signals are transmitted to various drip sites.

The monthly $\delta^{18}O_p$ values show negative correlation with surface air temperature at all the cave sites except Shihua Cave, which is opposite to that expected from the temperature effect. In addition, although the monthly $\delta^{18}O_p$ values are negatively correlated with precipitation at all the cave sites, only three sites are significant at the 95% level. These indicate that, due to the various vapor sources, a large portion of variability in $\delta^{18}O_p$ in the MRC cannot be explained simply by either temperature or precipitation alone.

All the thirty-four drip sites are classified into three types based on the $\delta^{18}O_d$ variability. About 82% of them are static drips with little discernable variation in $\delta^{18}O_d$ through the whole study period, but the drip rates of these drips are not necessary constant. Their discharge modes are site-specific and the oxygen isotopic composition of the stalagmites growing from them may record the average of multi-year climatic signals, which are modulated by the seasonality of recharge and potential effects of evaporation, and in some cases infiltration from large rainfall events. About 12% of the thirty-four drip sites are seasonal drips, although the amplitude of $\delta^{18}O_d$ is narrower than that of $\delta^{18}O_p$, the monthly response of $\delta^{18}O_d$ to coeval precipitation is not completely damped, and some of them follow the seasonal trend of $\delta^{18}O_p$ very well. These drips may be mainly recharged by present-day precipitation, mixing with some stored water. Thus, the stalagmites growing under them may record portions of the seasonal climatic signals embedded in $\delta^{18}O_p$. About 6% of the thirty-four drip sites are

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medium-variability drips, with constant and relatively low $\delta^{18}O_d$ values in the wet season, but with variable and relatively high $\delta^{18}O_d$ values in the dry season, reflecting flow switching in the karst or evaporation inside the cave.

Keywords: Eight caves in China; Three-year cave monitoring; Stable isotopes of precipitation and drip water

1. INTRODUCTION

The oxygen isotopic composition of speleothems ($\delta^{18}O_s$) has been used to interpret variations of past climate and atmospheric circulation (e.g. Dorale et al., 1992; McDermott et al., 1999, 2001; Wang et al., 2001, 2005; Fleitmann et al., 2003; Genty et al., 2003, 2006; Yuan et al., 2004; Spötl et al., 2006; Hu et al., 2008; Zhang et al., 2008; Cheng et al., 2009; Ma et al., 2012; Moseley et al., 2014; Duan et al., 2016). Now, with the development of high resolution sampling methods and *in situ* measurements, several studies have detected seasonally variable $\delta^{18}O_s$ which were used to explore sub-annual climatic and cave environmental signals (Kolodny et al., 2003; Treble et al., 2005, 2007; Johnson et al., 2006; D. Liu et al., 2008; Orland et al., 2009, 2012, 2014). These studies are always based on the assumption that the $\delta^{18}O_s$ broadly reflects that of the local precipitation. Consequently, when the climatic significance of $\delta^{18}O_s$ is interpreted, the isotope effects (Dansgaard, 1964) that control the oxygen isotopic composition of precipitation ($\delta^{18}O_p$) are often used. $\delta^{18}O_s$ profiles from low-latitude caves are mostly used as a proxy of local rainfall amount (Neff et al., 2001; Bar-Matthews et al., 2003; Fleitmann et al., 2004; Baker et al., 2007), whereas that from mid-high latitudes, especially in Europe, usually have been interpreted as a proxy of temperature (Lauritzen, 1995; McDermott et al., 1999, 2001; Onac et al., 2002; Genty et al., 2003, 2006; Spötl et al., 2006; Moseley et al., 2014). In addition, $\delta^{18}O_s$ has also been interpreted as variations in monsoon intensity (Wang et al., 2001, 2008; Yuan et al., 2004; Cheng et al., 2009), changes in moisture sources (Cruz, 2005; Cruz et al., 2006; Maher, 2008; LeGrande and Schmidt, 2009; Clemens et al., 2010; Dayem et al., 2010) and atmosphere circulation (Tan, 2014). In this context, the climatic signals embedded in $\delta^{18}O_s$ vary regionally, and can also be controversial, especially for Chinese $\delta^{18}O_s$ records (Clemens et al., 2010; Dayem et al., 2010; Johnson, 2011; Pausata et al., 2011; Lee et al., 2012; Wang and Chen, 2012; Tan, 2014; Z. Liu et al., 2014). Thus, to correctly interpret the climatic signals of $\delta^{18}O_s$, it is critical to identify the relative importance of the factors affecting the corresponding $\delta^{18}O_p$.

During the transmission from precipitation to drip water, processes such as seasonality of recharge (Bar-Matthews et al., 1996; Jones et al., 2000; Jones and Banner, 2003; Pape et al., 2010), mixing of water parcels of different ages (Yonge et al., 1985; Ayalon et al., 1998; Williams and Fowler, 2002; McDermott, 2004; Fairchild et al., 2006; Lachniet, 2009; Joe Lambert and Aharon, 2010; Li et al., 2011; Genty et al., 2014; Baldini et al., 2015; Comas-Bru and McDermott, 2015), evaporation in the soil and epikarst zone (Bar-Matthews et al., 1996; Ayalon et al., 1998; Denniston et al., 1999; Tang and Feng, 2001; Carrasco et al., 2006; Luo and Wang, 2008; Bradley et al., 2010; Wackerbarth et al., 2010; Cuthbert et al., 2014a; Comas-Bru and McDermott, 2015) and evaporation inside the cave (Ingraham et al., 1990; Caballero et al., 1996; Carrasco et al., 2006; Oster et al., 2012; Cuthbert et al., 2014b; Zeng et al., 2015), may modify the original signal of $\delta^{18}O_p$.

In previous research, the oxygen isotopic composition of drip waters ($\delta^{18}O_d$) has been found to (1) represent the annual or more long-term weighted average value of local $\delta^{18}O_p$ (Yonge et al., 1985; Caballero et al., 1996; Williams and Fowler, 2002; McDermott, 2004; Onac et al., 2008; Li et al., 2011; Riechelmann et al., 2011; Genty et al., 2014), (2) mirror the seasonal isotopic variations of surface precipitation (Li et al., 2000; Cruz, 2005; Van Beynen and Febbroriello, 2006; Cobb et al., 2007; Fuller et al., 2008; Genty, 2008), (3) just respond to the heavy rain events in the wet season (Bar-Matthews et al., 1996; Jones et al., 2000; Jones and Banner, 2003; Pape et al., 2010), or, (4) in arid regions, record the extent of evaporative enrichment of the drip water that occurs between recharge events (Cuthbert et al., 2014a). These studies cited above mainly focus on one cave or several caves in one area. As the karst process is complicated and individual, the $\delta^{18}O_d$ within a single cave even show some differences between each other (Bar-Matthews et al., 1996; Ayalon et al., 1998; Williams and Fowler, 2002; Van Beynen and Febbroriello, 2006; Luo et al., 2014; Genty et al., 2014). This would result in stalagmites formed from those isotopically different drip waters recording divergent palaeoclimatic signals. In general, the variations of $\delta^{18}O_d$ mostly depend on the specific discharge system rather than the climatic regime. Thereby, a detailed site-specific investigation of the relationship between large-scale climate, $\delta^{18}O_p$ variability, cave hydrology, and the $\delta^{18}O_d$ variability of different types of drip sites is essential to accurately interpret $\delta^{18}O_s$ signals.

This study aims to investigate the seasonal variations of $\delta^{18}O_p$ at a regional scale in the monsoon regions of China (MRC) and how the isotopic signals are transmitted to a variety of drip sites. An approximately three-year-long (May-2011 to April-2014) on-site rainfall and drip water monitoring program has been carried out with monthly to bi-monthly sampling intervals at eight caves in the MRC. Listed from south to north, the eight caves are Xianren cave (XR) in Yunnan Province, Baojinggong Cave (BJG) in Guangdong Province, Liangfeng cave (LF) in Guizhou Province, Furong cave (FR) in Chongqing, Penglaixian cave (PLX) in Anhui Province, Heshang cave (HS) in Hubei Province, Wanxiang cave (WX) in Gansu Province and Shihua cave (SH) in Beijing (Fig. 1).