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Rainfall and cave water isotopic relationships in two South-France sites

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Abstract

This article presents isotopic measurements ($\delta^{18}O$ and δD) of precipitation and cave drip water from two sites in southern France in order to investigate the link between rainfall and seepage water, and to characterize regional rainfall isotopic variability. These data, which are among the longest series in France, come from two rainfall stations in south-west France (Le Mas 1996–2012, and Villars 1998–2012; typically under Atlantic influence), and from one station in the south-east (Orgnac 2000–2012; under both Mediterranean and Atlantic influence). Rainfall isotopic composition is compared to drip water collected under stalactites from the same sites: Villars Cave (four drip stations 1999–2012) in the south-west, and Chauvet Cave (two drip stations 2000–2012) in the south-east, near Orgnac. The study of these isotopic data sets allows the following conclusions to be drawn about the rainfall/drip water relationships and about rainfall variability: (1) the cave drip water isotopic composition does not show any significant changes since the beginning of measurements; in order to explain its isotopic signature it is necessary to integrate weighted rainfall $\delta^{18}O$ of all months during several years, which demonstrates that, even at shallow depths (10–50 m), cave drip water is a mixture of rain water integrated over relatively long periods, which give an apparent time residence from several months to up to several years. These results have important consequences on the interpretation of proxies like speleothem fluid inclusions and tree-ring cellulose isotopic composition, which are used for paleoclimatic studies; (2) in the Villars Cave, where drip stations at two different depths were studied, lower $\delta^{18}O$ values were observed in the lower galleries, which might be due to winter season overflows during infiltration and/or to older rain water with a different isotopic composition that reaches the lower galleries after years; (3) local precipitation is characterized by local meteoric water lines, LMWL, with $\delta^{18}O/\delta D$ slopes close to 7 in both areas, and correlations between air temperature and precipitation $\delta^{18}O$ are low at both monthly and annual scales, even with temperature weighted by the amount of precipitation; (4) the mesoscale climate model REMOiso, equipped with a water isotope module, allows the direct comparison of modeled and

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observed long term water isotope records. The model slightly overestimates rainfall $\delta^{18}O$ at the respective sampling stations. However, it simulates very well not only the seasonal rainfall isotopic signal but also some intra-seasonal patterns such as a typical double-peak $\delta^{18}O$ pattern in winter time.

1. INTRODUCTION

The isotopic composition ($\delta^{18}O$ and δD) of precipitation is a key parameter used to better understand the present-day atmospheric circulation and, when dealing with fossil waters, of past periods (Sturm et al., 2005). Precipitation $\delta^{18}O$ is often the controlling factor for the isotopic composition of paleo-archives used to reconstruct the climate of the past: for example, precipitation $\delta^{18}O$ controls a large part of the isotopic composition of speleothem calcite (Wang et al., 2001; McDermott, 2004; McDermott et al., 2011), lake ostracod calcite (von Grafenstein et al., 1996), tree-ring cellulose (McCarroll and Loader, 2004; Treydte et al., 2007), soil secondary calcite (Marlin et al., 1993), human teeth (Daux et al., 2005), landsnails (Lecolle, 1983, 1985), beetles (van Hardenbroek et al., 2012), and other archives where the water molecule is involved. Besides, direct records of past precipitation $\delta^{18}O$ can be obtained from ice cores from Greenland, Antarctica and continental glaciers, as well as from fossil waters found in aquifers (Rozanski and Dulinski, 1987) or in fluid inclusions trapped in speleothems (Vonhof et al., 2006), which are composed of fossil precipitation water. The latter can be used to reconstruct past temperatures with the help of speleothem calcite $\delta^{18}O$ and clumped-isotope $\Delta 47$ measurements (Daeron et al., 2011). Consequently, measurements of precipitation $\delta^{18}O$ open the possibility of calculating past continental climate parameters such as temperature, humidity or precipitation $\delta^{18}O$, which are closely linked to air circulation patterns.

Long precipitation $\delta^{18}O$ time series allow the comparison of the isotopic signal with meteorological measurements and the calibration of proxy records (Anderson et al., 2002). Since long local measurement series are not always available, model simulations can be used instead to investigate the link between precipitation and the isotopic proxy. However such an approach needs careful evaluation of the respective proxy forward model. Atmospheric circulation, cloud physics, in particular the role of convective precipitation, and atmosphere-surface interactions have a strong influence on water isotope composition and need to be validated in order to extend the modeled relationships between the water isotopes and various climate parameters to the distant climatic past. A large number of general circulation models are equipped with water isotope modules, allowing the computation of $\delta^{18}O$ and δD patterns of all water reservoirs represented by the respective model (Joussaume et al., 1984; Hoffmann et al., 2000; Schmidt et al., 2007). More recently, high-resolution mesoscale models (potentially with a spatial resolution of ~15 km) were fitted with such isotope modules as well (Sturm et al., 2007; Sjolte et al., 2011). Long time series of $\delta^{18}O$ are of primary importance to verify and test the models' capacity to represent crucial features of the hydrological cycle on seasonal, interannual and decadal time scales.

Although it is well known that cave drip water $\delta^{18}O$ is controlled by precipitation $\delta^{18}O$, the temporal relationship between them is still not well constrained because long monitoring series of both drip waters and local rainfall are rare. The main questions are: which months contribute to the underground recharge that feeds stalactites? What is the average residence time of the mixing reservoir in the soil and bedrock before the water reaches the cave? Several recharge models involving diffuse and fracture flows linked to the great variety of porosity in karst formation hosting the cave have been proposed (Fairchild and Baker, 2012). These models were developed based on (1) geochemical data of drip water (i.e. Mg/Ca; (Tooth and Fairchild, 2003; Fairchild et al., 2006)); (2) fluorescent dye experiments, which are rare because of the complexity of the fracture network (Bottrell and Atkinson, 1992); and (3) the study of water isotopes ($\delta^{18}O$, δD and tritium).

Isotope time series of both rainfall and cave drip water at the same place during several months or years have been investigated in only a few studies. Most of these have revealed that isotope ratios in the cave drip water are very stable compared to the well-marked seasonal changes of the rain water, as in Carlsbad Cavern, New Mexico (Chapman et al., 1992), Waitomo Cave, New-Zealand (Williams and Fowler, 2002), in Bunker Cave, Germany (Kluge et al., 2010), and Nerja cave, Spain (Caballero et al., 1996). In some specific caves, a significant seasonal $\delta^{18}O$ variation is detected in the dripwater because of evaporation processes in the soil and epikarst, like in Soreq Cave, Israel (Bar-Matthews et al., 1996) or mid-western USA caves (Denniston et al., 1999). Strong rainfall events and a rapid connection through the epikarst zone, as is the case with Santana Cave, Brazil (Cruz et al., 2005) or on Socotra Island, Yemen (van Rampelbergh et al., 2013) can also cause seasonal variability. The conclusion of most studies is that cave drip water $\delta^{18}O$ is close to the weighted mean precipitation $\delta^{18}O$ of the year (Yonge et al., 1985; Williams and Fowler, 2002); however, since most time series are short (i.e. from a few months to 2–4 years of monitoring), no modeling has been attempted to closely link rain and cave $\delta^{18}O$ values and to give an average residence time of the water in the karstic zone above the cave.

This article presents the results of stable oxygen and hydrogen isotope monitoring in precipitation at three sites in the south of France: Le Mas, Villars and Orgnac (Fig. 1). Close to these sites, the drip water from several stalactites was monitored in two caves which are known for their prehistoric remains and for their speleothem-based paleoclimatic reconstructions: Villars Cave and Chauvet