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Calibration of speleothem δ[18]O records against hydroclimate instrumental records in Central Brazil

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ABSTRACT

δ[18]O in speleothems is a powerful proxy for reconstruction of precipitation patterns in tropical and sub-tropical regions. The aim of this study is to calibrate the δ[18]O record of speleothems against historical precipitation and river discharge data in central Brazil, a region directly influenced by the Southern Atlantic Convergence Zone (SACZ), a major feature of the South American Monsoon System (SAMS). The present work is based on a sub-annual resolution speleothem record covering the last 141 years (the period between the years 1870 and 2011) from a cave in central Brazil. The comparison of this record with instrumental hydroclimate records since 1921 allows defining a strong relationship between precipitation variability and stable oxygen isotope ratios from speleothems. The results from a monitoring program of climatic parameters and isotopic composition of rainfall and cave seepage waters performed in the same cave, show that the rain δ[18]O variability is dominated by the amount effect in this region, while δ[18]O drip water remains almost constant over the monitored period (1.5 years). The δ[18]O of modern calcite, on the other hand, shows clear seasonal variations, with more negative values observed during the rainy season, which implies that other factors also influence the isotopic composition of carbonate. However, the relationship between δ[18]O of carbonate deposits and rainwater is supported by the results from the comparison between speleothem δ[18]O records and historical hydroclimate records. A significant correlation between speleothem δ[18]O and monsoon rainfall variability is observed on sub-decadal time scales, especially for the monsoon period (DJFM and NDJFM), once the rainfall record have been smoothed with a 7–9 years running mean. This study confirms that speleothem δ[18]O is directly associated with monsoon rainfall variability in central Brazil. The relationship between speleothem δ[18]O records and hydroclimatic historical records allows approximation of the absolute changes in mean annual rainfall during the last millennia in the SACZ/SAMS domain.

1. Introduction

Speleothem isotope records are considered one of the most robust proxy for precipitation in (sub)tropical regions (Fairchild et al., 2006). Because of its large karstic area, Brazil is one of the countries with highest potential for reconstruction of the South American Monsoon System (SAMS) based on speleothem isotope records (e.g. Cruz et al., 2005a, 2005b; Wang et al., 2006; Cruz et al., 2006; Wang et al., 2007; Strikis et al., 2011; Novello et al., 2012a, 2012b; Apaestegui et al., 2014). One of the main features of the SAMS is the South Atlantic Convergence Zone (SACZ), a NW-SE band of convective activity, which extends from central Amazon basin to the South Atlantic Ocean (Fig. 1).

The SACZ activity is widely documented in contemporaneous climatology (e.g., Robertson and Mechoso, 2000; Vera et al., 2006; Junquas et al., 2013), but its multidecadal to centennial variability remains poorly known because of the low quantity of high-resolution and precisely dated paleoclimate records within the area influenced by the SACZ (Prado et al., 2013). In South America many proxies have been analyzed to document paleoclimate variability,

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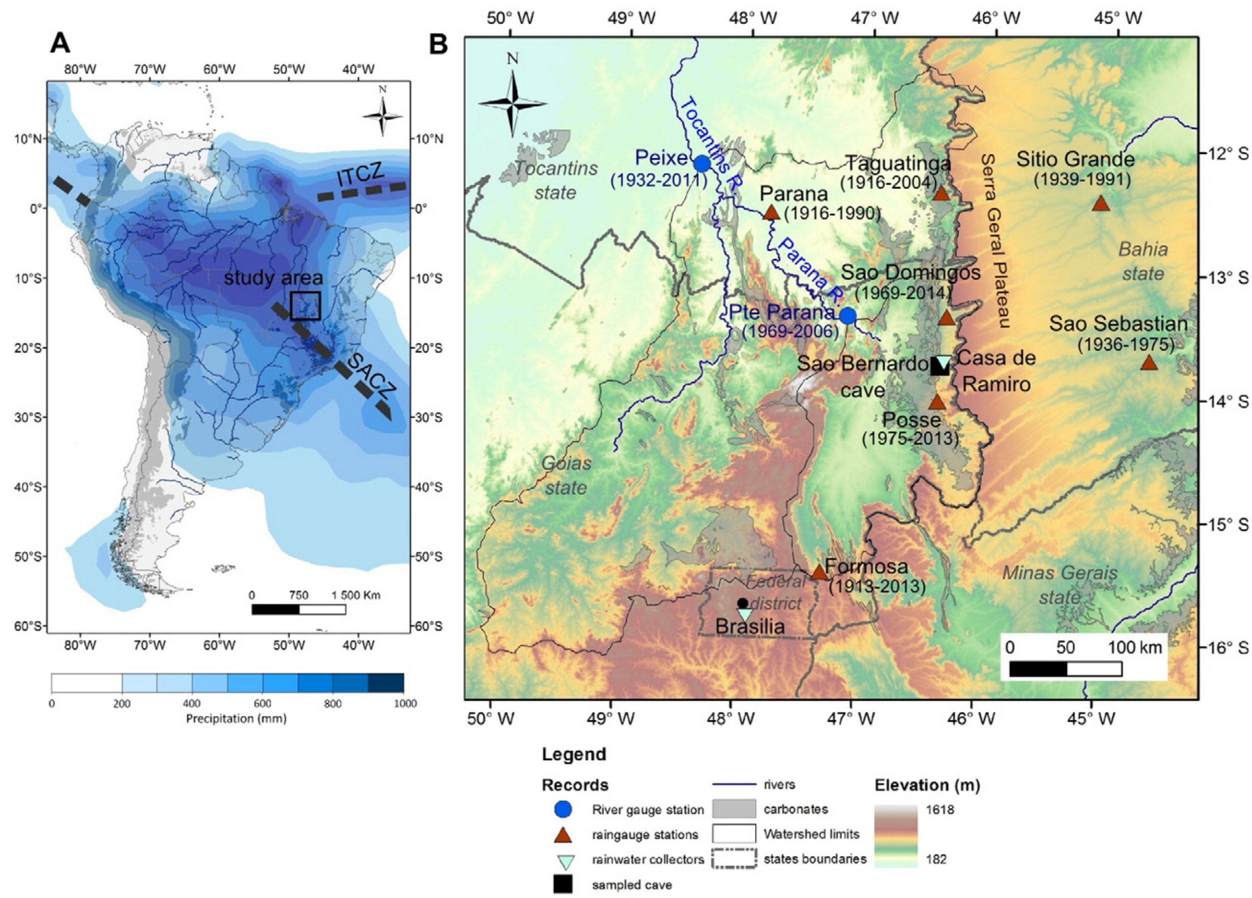

Fig. 1. A) Long-term (1979–2000) mean precipitation (in mm) for December–February (DJF) from the Climate Prediction Center Merged Analysis of Precipitation (website: http://www.cpc.ncep.noaa.gov/) and location of the study area. B) Location of the sampled cave, the hydrologic gauge station, the rain gauge stations and the rainwater collectors stations used in this study. Carbonate lithology is reported from CPRM geological 1/1000000 maps (2004).

including ice cores (e.g. Thompson et al., 2013), lake sediments (e.g. Cordeiro et al., 2011; Sifeddine et al., 2011), tree rings (e.g. Brienen et al., 2012; Ferrero et al., 2015) and marine cores (e.g. Haug et al., 2003; Chiessi et al., 2009). Stable isotope records from carbonate speleothems, however, have been the most widely used for reconstructing paleo-precipitation variability at high temporal resolution and over timescales varying from the last millennia (Vuille et al., 2012; Novello et al., 2012a, 2012b; Apaestegui et al., 2014) to the Holocene (Strikis et al., 2011; Kanner et al., 2013) and orbital timescales (Cruz et al., 2005a, 2005b, 2006; Wang et al., 2007; Cheng et al., 2013). These proxy records also provide an ideal testbed for climate models (e.g. Vuille et al., 2003; Dias de Melo and Marengo, 2008; Braconnot et al., 2007; Khodri et al., 2009), allowing for stringent tests of their performance and ability to reproduce observed climate variability on a range of spatial and temporal scales.

Most speleothem-based paleoclimatic studies in South America focused on the carbonate $\delta^{18}O$ variability, and interpreted these changes as a function of relative changes in precipitation amount (e.g. Reuter et al., 2009; Strikis et al., 2011; Novello et al., 2012a, 2012b), changes in the relative proportion of moisture supplied from different source areas, such as the Atlantic ocean or the Amazon basin (Cruz et al., 2005a, 2006) or simply as an intensification of the monsoon regime (Kanner et al., 2013; Apaestegui et al., 2014). However, only few monitoring programs related to climatic, hydrological and geochemical parameters have been performed in South American caves yet (Sondag et al., 2003; Cruz et al., 2005b) and none of them attempted to calibrate the isotopic records against historical precipitation records. The calibration of speleothem $\delta^{18}O$ records as a function of climate parameter allows determining the main environmental parameters controlling stable isotopes in speleothems in order to avoid misinterpretation of $\delta^{18}O$ records during climate reconstruction (Baker et al., 2007; Mattey et al., 2008; Jex et al., 2011; Tremaine et al., 2011a, 2011b). However, the calibration studies are usually too short to ensure that a climate relationship embedded in the $\delta^{18}O$ of carbonate speleothems is maintained and applicable to a long-term perspective. One of the reasons for this problem is that the residence time of cave percolating waters can be relatively long (Genty et al., 2014). In this context it is essential to directly establish and verify a quantitative relationship between historical climate and speleothem isotope records. However, it is very difficult to obtain well-dated speleothem records with a resolution that allows resolving interannual climate variability derived from $\delta^{18}O$ archives (Orland et al., 2014), given that most speleothems are not characterized by fast growth (rates of several $mm \cdot year^{-1}$) and present U/Th age errors larger than 10 years for the last century.

Comparing speleothem records with hydrological/climatic historical records allows investigating the coherence between speleothem $\delta^{18}O$ variations and changes in modern rainfall distribution (Yadava et al., 2004; Treble et al., 2005; Mattey et al., 2008; Cai et al., 2010; Baker et al., 2007; Jex et al., 2010, 2011). In the current literature this approach is quite common and generally performed using records that are 40–50 years long, as longer historic precipitation records are often not available. The relationship obtained over this modern calibration period is then used to estimate the magnitude of abrupt changes in absolute precipitation amounts, which may have culminated in social crisis throughout history, for instance the drought period at the time of the collapse of the Maya civilization in Mexico during the Medieval Climate Anomaly (Medina-Elizalde and Rohling, 2012).