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Precipitation changes over the eastern Bolivian Andes inferred from speleothem ($\delta^{18}O$) records for the last 1400 years

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ABSTRACT

Here we present high-resolution $\delta^{18}O$ records obtained from speleothems collected in the eastern Bolivian Andes. The stable isotope records are related to the regional- to large-scale atmospheric circulation over South America and allow interpreting changes in $\delta^{18}O$ during the last 1400 yr as a function of changes in precipitation regimes over the southern tropical Andes. Two distinct phases with more negative $\delta^{18}O$ values, interpreted as periods of increased convective activity over the eastern Andean Cordillera in Bolivia are observed concomitantly with periods of global climate anomalies during the last millennium, such as the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA) respectively. Changes in the Bolivian $\delta^{18}O$ record during the LIA are apparently related to a southward displacement of the Intertropical Convergence Zone (ITCZ), which acts as a main moisture driver to intensify convection over the tropical continent. During the MCA, however, the increased convective activity observed in the Bolivian record is likely the result of a different mechanism, which implies moisture sourced mainly from the southern tropical Atlantic. This interpretation is consistent with paleoclimate records further to the north in the tropical Andes that show progressively drier conditions during this time period, indicating a more northerly position of the ITCZ. The transition period between the MCA and the LIA shows a slight tendency toward increased $\delta^{18}O$ values, indicating weakened convective activity. Our results also reveal a non-stationary anti-phased behavior between the $\delta^{18}O$ reconstructions from Bolivia and northeastern Brazil that confirms a continental-scale east–west teleconnection across South America during the LIA.

1. Introduction

Several studies have revealed that important changes occurred in the mean state of the South American Monsoon System (SAMS) during the last millennium, including the period corresponding to the Medieval Climate Anomaly (MCA, ∼900–1100 C.E.) and the Little Ice Age (LIA, ∼1500–1850 C.E.) (e.g. Bird et al., 2011; Kanner et al., 2013; Novello et al., 2012, 2016; Vuille et al., 2012; Apaéstegui et al., 2014). Reconstructions based on oxygen isotopes ($\delta^{18}O$) from lacustrine sediments, speleothems and ice core records document that the MCA was characterized by higher values of $\delta^{18}O$, suggesting a weakened SAMS in the Andes. In contrast, the LIA shows opposite conditions with lower $\delta^{18}O$ values that suggest a period of increased SAMS activity (Reuter et al., 2009;

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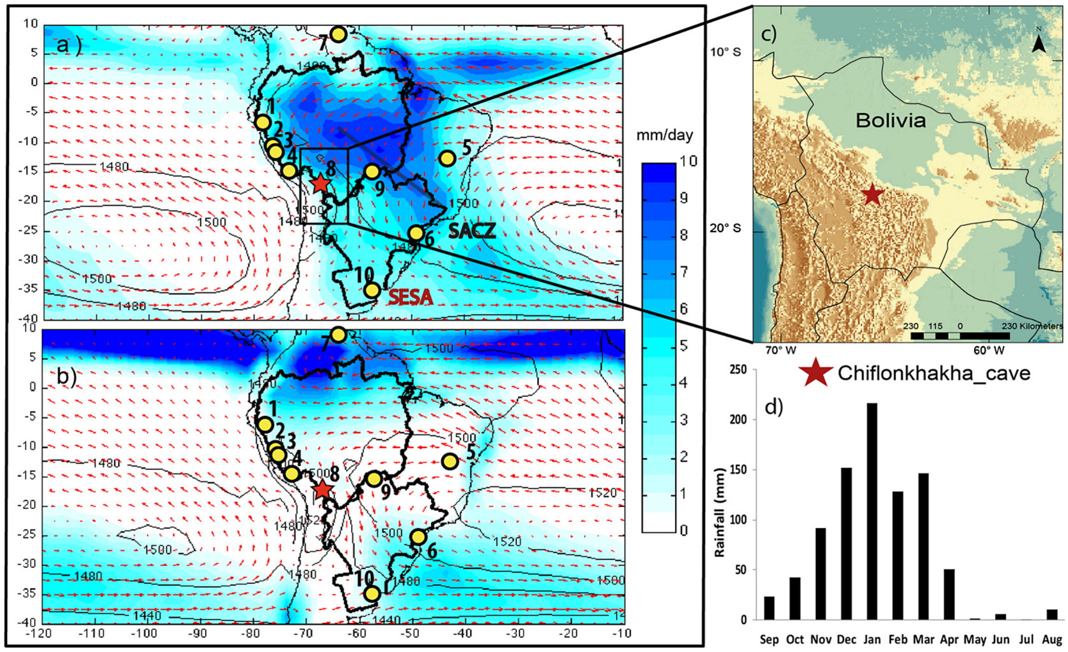

Fig. 1. Geopotential height (contours, in geopotential meters – gpm) and total wind at 850 hPa from ERA-40 for the 1975–2002 period and mean daily rainfall (shading) from CMAP data for the 1979–2002 period. Panel (a) shows DJF season; (b) JJA season. Limits of the Amazon and La Plata basins are shown. The numbers in the Figure indicate locations of SESA – SACZ areas and proxy records in South America: (1) Palestina cave record (Apaéstegui et al., 2014); (2) Pumacocha lake record (Bird et al., 2011); (3) Huagapo cave record (Kanner et al., 2013); (4) Quelccaya Ice Cap (Thompson et al., 2013); (5) DV2 cave record (Novello et al., 2012); (6) Cristal cave record (Vuille et al., 2012); (7) Titanium record from Cariaco Basin (Haug et al., 2001); (8) Bolivian record (this study). (9) Pau d'Alho Cave record (Novello et al., 2016); (10) GeoB 13813-4 record (Perez et al., 2016); Panel (c) shows the location of the Umajalanta–Chiflonkhakha cave system. (d) Monthly mean precipitation recorded at the Torotoro meteorological station (1999–2004).

Bird et al., 2011; Kanner et al., 2013; Vuille et al., 2012; Apaéstegui et al., 2014). These changes in SAMS intensity were associated with displacements of the Intertropical Convergence Zone (ITCZ) to the south during the LIA and to the north during the MCA (Haug et al., 2001).

The regional coherence among isotopic records from the tropical Andes during the LIA indicates a large-scale intensification of the SAMS at that time. During the MCA, however, the magnitude of the isotopic excursion appears to be dependent on latitude with a stronger isotopic signal at lower latitudes ($<10°$S). This north–south gradient seen in the isotopic records during the MCA has been attributed to changes in the winter contribution to total annual precipitation (Apaéstegui et al., 2014). Nevertheless, there is a need for additional paleoclimate reconstructions from the tail end of the SAMS in the southern tropical Andes to compare with more northern records, in particular during the MCA. The lack of records to adequately reconstruct the regional climate response to the radiative forcing anomalies during the LIA and MCA (Bird et al., 2011; Novello et al., 2016) has complicated advancing our understanding of the underlying dynamical mechanisms involved in changing the tropical South American rainfall patterns and the SASM mean state. In order to better document how external forcing affected the SAMS variability and to understand the underlying mechanisms, it is necessary to develop a denser network of proxy records.

The current understanding of climate variability in South America is growing rapidly as discussed in several recent reviews (e.g. Zhou and Lau, 1998; Vera et al., 2006; Garreaud et al., 2009; Marengo et al., 2012). The atmospheric dynamics associated with occurrence of extreme precipitation events in the southwestern Amazon basin and especially over Bolivia were discussed in Espinoza et al. (2014). These events are associated with intense flooding over the southwestern Amazon, while at the same time dry conditions persist in southeastern Brazil, which, in some instances, have led to profound crises in water supply for agriculture, energy production and lack of drinking water and sanitation for the population of the largest cities in Brazil (Coelho et al., 2015). This out of phase relationship between extreme precipitation over the western Amazon and drought over southeastern Brazil has been systematically analyzed for the last three decades by Cavalcanti et al. (2016). Documenting and understanding continental-scale rainfall teleconnections for longer timescales (e.g. over the last millennium), would go a long way in analyzing the proxy network over the South American monsoon region in a dynamically more meaningful and plausible way.

In order to document past precipitation changes along the eastern slope of the southern tropical Andes, we developed stable isotope time series ($\delta^{18}O$) from Bolivian speleothems (65.77°W; 18.12°S, 2650 m.a.s.l.; Fig. 1a). Our site represents the first speleothem record published from Bolivia and it is also the southernmost isotopic record from the tropical Andes. Indeed, it allows exploration of atmospheric teleconnections when compared and synthesized with other regional records in South America. The eastern Bolivian Andes are subject to extreme precipitation seasonality as they are located at the most distal site influenced by the SAMS, where precipitation occurs almost exclusively during the mature phase of the summer monsoon season in November–March (NDJFM; Garreaud et al., 2003).

2. Climatic conditions along the eastern slopes of the southern tropical Andes

The Umajalanta–Chiflonkhakha cave system (65.77 W; 18.12°S; 2650 m.a.s.l.) (Fig. 1c) represents the largest cave system in the Bolivian territory and one of the few locations with occurrence of suitable speleothems for paleoclimate reconstruction. These caves are formed in the cretaceous limestone bank of the "Miraflores" formation located in the Torotoro National Park in the Department of Potosi; a rare example of karst terrain in Bolivia. It is known as the Umajalanta–Chiflonkhakha karst system, extending