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Late Quaternary environmental change in the interior South American tropics: new insight from leaf wax stable isotopes

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ABSTRACT

Stable isotope analysis of leaf waxes in a sediment core from Laguna La Gaiba, a shallow lake located at the Bolivian margin of the Pantanal wetlands, provides new perspective on vegetation and climate change in the lowland interior tropics of South America over the past 40,000 years. The carbon isotopic compositions ($\delta^{13}C$) of long-chain *n*-alkanes reveal large shifts between C_3- and C_4-dominated vegetation communities since the last glacial period, consistent with landscape reconstructions generated with pollen data from the same sediment core. Leaf wax $\delta^{13}C$ values during the last glacial period reflect an open landscape composed of C_4 grasses and C_3 herbs from 41–20 ka. A peak in C_4 abundance during the Last Glacial Maximum (LGM, ∼21 ka) suggests drier or more seasonal conditions relative to the earlier glacial period, while the development of a C_3-dominated forest community after 20 ka points to increased humidity during the last deglaciation. Within the Holocene, large changes in the abundance of C_4 vegetation indicate a transition from drier or more seasonal conditions during the early/mid-Holocene to wetter conditions in the late Holocene coincident with increasing austral summer insolation. Strong negative correlations between leaf wax $\delta^{13}C$ and δD values over the entire record indicate that the majority of variability in leaf wax δD at this site can be explained by variability in the magnitude of biosynthetic fractionation by different vegetation types rather than changes in meteoric water δD signatures. However, positive δD deviations from the observed $\delta^{13}C$–δD trends are consistent with more enriched source water and drier or more seasonal conditions during the early/mid-Holocene and LGM. Overall, our record adds to evidence of varying influence of glacial boundary conditions and orbital forcing on South American Summer Monsoon precipitation in different regions of the South American tropics. Moreover, the relationships between leaf wax stable isotopes and pollen data observed at this site underscore the complementary nature of pollen and leaf wax $\delta^{13}C$ data for reconstructing past vegetation changes and the potentially large effects of such changes on leaf wax δD signatures.

1. Introduction

Characterizing the controls on South American Summer Monsoon (SASM) dynamics on geological timescales provides critical context for investigating present and future trends in South American tropical climate. Changes in the distribution and intensity of SASM precipitation can alter hydrologic and vegetation patterns across much of the South American continent with potentially significant ramifications for both the global carbon cycle and climate system. An increasingly coherent picture of late Quaternary SASM behavior has begun to emerge from a number of records of SASM precipitation from the Central Andes, western Amazonia and southern Brazil (Cruz et al., 2005; Wang et al., 2007; Kanner et al., 2012; Mosblech et al., 2012; Cheng et al., 2013; Fornace et al., 2014). These records indicate that generally wet conditions prevailed during the Last Glacial Maximum (LGM) and late glacial period, followed by a shift towards drier conditions in the early/mid-Holocene. After this dry period, SASM precipitation has gradually increased into the present, a trend widely attributed to increasing summer insolation through the Holocene (e.g., Bird et al., 2011).

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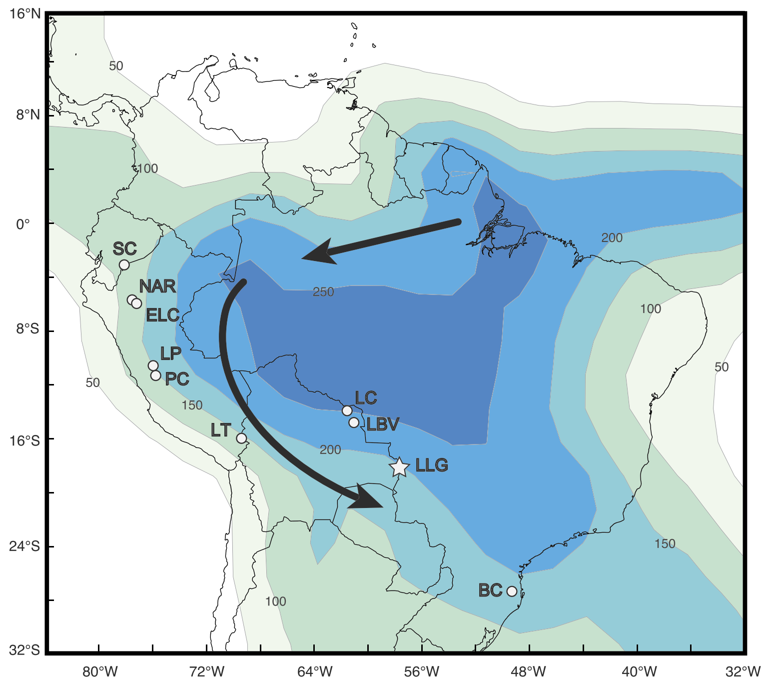

Fig. 1. Map of South American tropics with sites discussed in text and average January precipitation (mm/month, 1981–2010). Contours indicate increments of 50 mm/month; precipitation data are from CAMS_OPI monthly precipitation dataset (NCEP). Study site Laguna La Gaiba (LLG) is marked with a star; other sites include Santiago Cave (SC; Mosblech et al., 2012), Cueva del Diamante/El Condor (NAR/ELC; Cheng et al., 2013), Laguna Pumacocha (LP; Bird et al., 2011), Pacupahuain Cave (PC; Kanner et al., 2012), Lake Titicaca (LT; Baker et al., 2001; Fornace et al., 2014), Laguna Chaplin/Laguna Bella Vista (LC/LBV; Mayle et al., 2000, Burbridge et al., 2004), and BC (Botuverá Cave; Cruz et al., 2005; Wang et al., 2007). Arrows indicate general direction of moisture transport from tropics to subtropics during monsoon season.

Missing from this discussion of past SASM trends are critical records from the interior tropics, where climate archives such as lacustrine sediments or speleothems rarely extend back to the last glacial period. Available pollen records from several sites in the southern Amazon Basin point to drier conditions during the last glacial period (Mayle et al., 2000; Burbridge et al., 2004), suggesting a disconnect between the interior tropics and other regions. Several recent studies have focused on reconstructing hydrologic conditions in the Pantanal, a large wetland expanse primarily located in the Mato Grosso do Sul region of Brazil and roughly equidistant between the well-studied Central Andes and southern Brazil regions (Whitney et al., 2011; McGlue et al., 2012; Whitney and Mayle, 2012; Metcalfe et al., 2014). Evidence from pollen, diatoms and other biological proxies in a continuous ~45,000-yr sediment record from Laguna La Gaiba (LLG) suggest drier and cooler conditions in the Pantanal during the last glacial period (Whitney et al., 2011; Metcalfe et al., 2014). During the Holocene, hydrologic patterns in the Pantanal appear to be consistent with other SASM records, with a relatively dry early/mid-Holocene followed by wetter conditions in the late Holocene (Whitney et al., 2011; McGlue et al., 2012; Whitney and Mayle, 2012; Metcalfe et al., 2014). However, existing evidence of hydrologic change in the Pantanal derived from past biota assemblages is complicated by complex or non-specific relationships between climate and species distributions. Independent climate proxies can thus offer further insight into landscape and hydrologic changes in this region and allow for more robust comparison with other tropical South American records.

In this study, we use stable isotope analysis of terrestrial biomarkers in LLG sediments to better characterize environmental changes at this site and regional SASM precipitation patterns during glacial and interglacial periods. Specifically, we analyze the carbon ($\delta^{13}C$) and hydrogen (δD) isotopic compositions of leaf waxes, a suite of long-chain lipids produced by terrestrial and emergent aquatic vascular plants now commonly employed to reconstruct past climate change in a wide range of environments (see review by Eglinton and Eglinton, 2008). We use C_{27}–C_{33} *n*-alkane $\delta^{13}C$ to reconstruct changes in the distribution of C_3 vs. C_4 vegetation, which is controlled by a range of climatic factors, including atmospheric CO_2 concentration, temperature, and water availability (Ehleringer et al., 1997). In particular, the prevalence of C_4 vegetation at warm tropical or subtropical sites is often linked to drier or more seasonal conditions (Still, 2003). Leaf wax δD has been shown to reliably track trends in meteoric water δD, providing direct information about climatic trends. However, the relationship between meteoric water and leaf wax δD can be influenced by a number of secondary effects, including soil evaporation and leaf transpiration processes as well as variability in biosynthetic fractionation among different vegetation types (see review by Sachse et al., 2012). The combination of leaf wax $\delta^{13}C$ and δD data with detailed pollen information from the same sediment core thus provides a unique opportunity to investigate the fidelity of pollen and leaf wax $\delta^{13}C$ vegetation reconstructions and address outstanding questions about the effects of vegetation change on leaf wax δD signatures.

2. Background

2.1. Study site description

The Pantanal is a large (140,000 km^2) expanse of wetlands situated in a low-lying sedimentary basin in central western Brazil with smaller areas in Bolivia and Paraguay (Figs. 1, 2). The landscape of the basin mostly consists of large fluvial fans deposited by a number of rivers that flow from upland regions to the western side of the basin, eventually converging with the north–south flowing Paraguay River (Assine et al., 2015). Laguna La Gaiba (LLG, 17.75°S, 57.58°W) is a large, shallow lake (maximum area and depth of ~100 km^2 and 4–6 m, respectively) located along the upper Paraguay River (Fig. 2). The lake is also connected to the Corixo Grande River, which flows along the western border of the Pantanal basin towards the lake. In the present day, the lowland