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Quantitative estimates of tropical temperature change in lowland Central America during the last 42 ka

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ABSTRACT

Determining the magnitude of tropical temperature change during the last glacial period is a fundamental problem in paleoclimate research. Large discrepancies exist in estimates of tropical cooling inferred from marine and terrestrial archives. Here we present a reconstruction of temperature for the last 42 ka from a lake sediment core from Lake Petén Itzá, Guatemala, located at 17°N in lowland Central America. We compared three independent methods of glacial temperature reconstruction: pollen-based temperature estimates, tandem measurements of $\delta^{18}O$ in biogenic carbonate and gypsum hydration water, and clumped isotope thermometry. Pollen provides a near-continuous record of temperature change for most of the glacial period but the occurrence of a no-analog pollen assemblage during cold, dry stadials renders temperature estimates unreliable for these intervals. In contrast, the gypsum hydration and clumped isotope methods are limited mainly to the stadial periods when gypsum and biogenic carbonate co-occur. The combination of palynological and geochemical methods leads to a continuous record of tropical temperature change in lowland Central America over the last 42 ka. Furthermore, the gypsum hydration water method and clumped isotope thermometry provide independent estimates of not only temperature, but also the $\delta^{18}O$ of lake water that is dependent on the hydrologic balance between evaporation and precipitation over the lake surface and its catchment. The results show that average glacial temperature was cooler in lowland Central America by 5–10 °C relative to the Holocene. The coldest and driest times occurred during North Atlantic stadial events, particularly Heinrich stadials (HSs), when temperature decreased by up to 6 to 10 °C relative to today. This magnitude of cooling is much greater than estimates derived from Caribbean marine records and model simulations.
The extreme dry and cold conditions during HSs in the lowland Central America were associated with fresh water forcing in the North Atlantic, which led to reduced Atlantic Meridional Overturning Circulation, cooling of the North Atlantic, southern advance of sea-ice, and southward shift of the Intertropical Convergence Zone. Although some models correctly predict the sign of temperature and precipitation changes, they consistently underestimate the degree of observed cooling and decreased precipitation over land in lowland Central America.

1. Introduction

The tropics are important for controlling the global energy heat budget and water vapor content in the atmosphere, and are the dominant source of interannual climate variability today. However, the role of this region in past climate change on glacial-to-interglacial and millennial time scales is not well known (e.g., Clement and Peterson, 2008). Foremost is the question of the magnitude of temperature change in the tropics during the last glacial period, which has been debated by the scientific community since the 1980s (Rind and Peteet, 1985; Colinvaux et al., 1996). In the northern Neotropics, for example, large discrepancies exist in estimates of tropical cooling that are inferred from marine (~2 °C) and terrestrial (~6 °C) archives (Rind and Peteet, 1985; Colinvaux et al., 1996). To date only a few records exist and are based mainly on indirect temperature estimates derived from pollen and snowline depression (Leyden et al., 1994; Bush et al., 2009 and references therein; Roy and Lachniet, 2010; Correa-Metrio et al., 2012).

Here we present a new reconstruction of temperature and precipitation changes over the last 42 ka from a lake sediment core from Lake Petén Itzá, northern Guatemala, located at 17°N in low-

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Fig. 1. Map of the Intra American Seas showing the location of the Petén Lake District in northern Guatemala (after Bush et al., 2009). Stars indicate the position of cores from the Orca Basin (Gulf of Mexico) and Cariaco Basin (Caribbean) discussed in the text.

land Central America. Previous studies of sediment cores from Lake Petén Itzá showed that alternating layers of clay- and gypsum-rich sediment reflect times of wetter and drier conditions, respectively (Hodell et al., 2008). The glacial period was cooler and drier than the Holocene with the most arid conditions coinciding with Greenland stadials, especially those associated with Heinrich events. Pollen assemblages were dominated by xeric-tolerant taxa and the δ^{18}O values of ostracods were highest, indicating cold arid conditions (Hodell et al., 2008; Escobar et al., 2012; Correa-Metrio et al., 2012). In contrast, interstadials and the Last Glacial Maximum (LGM) contain pollen indicative of temperate pine–oak forest, indicating cool humid conditions (Bush et al., 2009; Correa-Metrio et al., 2012). The proxies from Lake Petén Itzá show a similar variability as observed in Greenland and sediments from the Cariaco Basin (Peterson et al., 2000), suggesting a consistent regional response to millennial-scale climate changes (Hodell et al., 2008).

To estimate the magnitude of temperature change during the last glacial period, Hodell et al. (2012) used tandem measurements of δ^{18}O in biogenic carbonate and gypsum hydration water to determine the δ^{18}O and δD of lake water and its temperature. The results suggested that temperatures were 6 to 10 °C colder than mean annual temperature in the region today during HS1. This cooling is far greater than observed in nearby marine sediment cores and in model simulations. To test the low temperatures derived by the gypsum hydration method, we applied clumped isotope thermometry as an independent tool to obtain both temperature and δ^{18}O of water from carbonate minerals. The derived temperatures are also compared with pollen-based temperature estimates using the Modern Analog Technique (MAT) (Correa-Metrio et al., 2012). The combination of all three methods provides a continuous record of tropical temperature change in lowland Central America over the last 42 ka.

2. Study site

We used a sediment core from Lake Petén Itzá, the largest and deepest lake in the Central Petén Lake district in northern Guatemala (16.55°N, 89.50°W) (Fig. 1). Epilimnetic temperatures reach ~30 °C during summer with a well-developed thermocline at about 30 m water depth, which persists through most of the year (Hillesheim et al., 2005; Pérez et al., 2010) (Fig. 2). The average hypolimnetic temperature is set by winter mixing and is on average ~25 °C. Today, the lake water has a high pH (~8) and a low total ionic concentration that is dominated by calcium, magnesium, sulphate, and bicarbonate ions. The modern lake water is saturated for calcium carbonate but under-saturated for gypsum (Hodell et al., 2006).

The mean oxygen and hydrogen isotopic composition of lake water today is ~2.7‰ and 15.2‰, respectively, and surface water is slightly more enriched during summer because of evaporation from the lake surface (Hodell et al., 2012) (Fig. 2).

The majority of precipitation falls during summer months (May–October) and is on average 1600 mm per year. In winter, the precipitation is low but polar air masses occasionally bring light winter rains (*nortes*) with cold fronts. The mean annual air temperature is 26 °C, with mean monthly air temperatures reaching as low as 19 °C during winter and as high as 31 °C during summer.

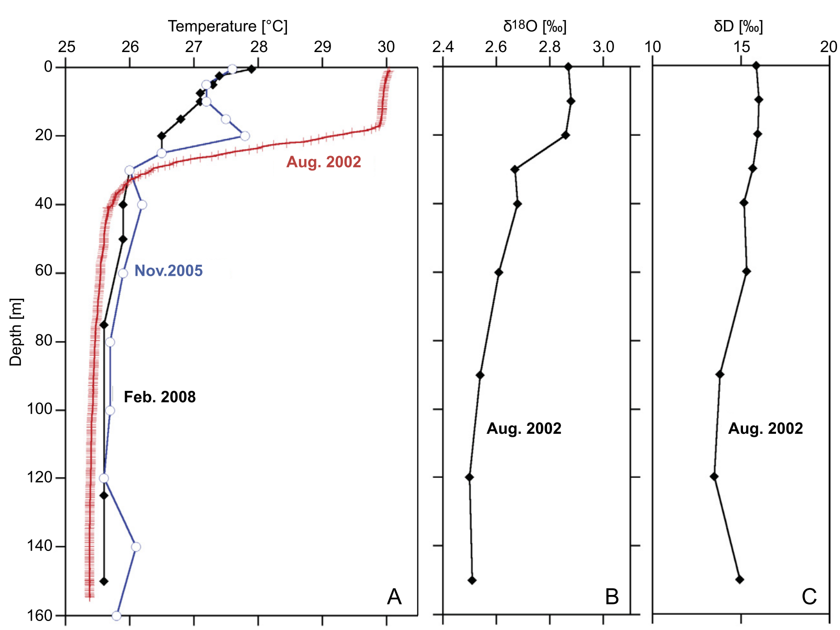

Fig. 2. Modern hydrographic profiles of Lake Péten Itzá: A) summer (red) and winter (blue, black) temperature; B) δ^{18}O and C) δD of lake water collected in August 2002 (Hodell et al., 2012, modified). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)