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Invited review

Nature and causes of Quaternary climate variation of tropical South America

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A B S T R A C T

This selective review of the Quaternary paleoclimate of the South American summer monsoon (SASM) domain presents viewpoints regarding a range of key issues in the field, many of which are unresolved and some of which are controversial. (1) El Niño-Southern Oscillation variability, while the most important global-scale mode of interannual climate variation, is insufficient to explain most of the variation of tropical South American climate observed in both the instrumental and the paleoclimate records. (2) Significant climate variation in tropical South America occurs on seasonal to orbital (i.e. multi-millennial) time scales as a result of sea-surface temperature (SST) variation and ocean—atmosphere interactions of the tropical Atlantic. (3) Decadal-scale climate variability, linked with this tropical Atlantic variability, has been a persistent characteristic of climate in tropical South America for at least the past half millennium, and likely, far beyond. (4) Centennial-to-millennial climate events in tropical South America were of longer duration and, perhaps, larger amplitude than any observed in the instrumental period, which is little more than a century long in tropical South America. These were superimposed upon both precession-paced insolation changes that caused significant variation in SASM precipitation and eccentricity-paced global glacial boundary conditions that caused significant changes in the tropical South American moisture balance. As a result, river sediment and water discharge increased and decreased across tropical South America, lake levels rose and fell, paleolakes arose and disappeared on the Altiplano, glaciers waxed and waned in the tropical Andes, and the tropical rainforest underwent significant changes in composition and extent.

To further evaluate climate forcing over the last glacial cycle (~125 ka), we developed a climate forcing model that combines summer insolation forcing and a proxy for North Atlantic SST forcing to reconstruct long-term precipitation variation in the SASM domain. The success of this model reinforces our confidence in assigning causation to observed reconstructions of precipitation. In addition, we propose a critical correction for speleothem stable oxygen isotopic ratios, which are among the most significant of paleoclimate proxies in tropical South America for reconstruction of variation of paleo-precipitation (or SASM intensity). However, it is already well known that any particular $\delta^{18}O$ value observed in speleothem carbonate is affected by two processes that have nothing to do with changes in precipitation amount—the influence of temperature on carbonate-water isotopic fractionation in the cave and the influence of changing $\delta^{18}O$ of seawater. Quantitatively accounting for both “artifacts” can significantly alter the interpretations of speleothem records. In tropical South America, both adjustments act in the same direction and have the tendency to increase the true amplitude of the paleo-hydrologic signal (but by different amounts in glacial and inter-glacial stages). These corrections have even graver implications for the interpretation of tropical Northern Hemisphere speleothem records (e.g. Chinese speleothems) where the combined adjustments tend to decrease or even eliminate the “true” signal amplitude.

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1. Introduction

Several reviews have been published concerning the Quaternary paleoclimate of tropical South America, including a recent edited volume on the topic (Vimeux et al., 2009). Thus, it would not be interesting, nor is it our intention, to produce an exhaustive recapitulation of the subject. Instead, in this selective review, we take the opportunity to offer our viewpoints and conclusions regarding a range of topics that we chose, because we believe they are key issues in the field yet still represent unsettled science.

We mostly limit our discussion to *tropical* South America and, more restrictively, to tropical South America from the Andes eastward and south of the equator (Fig. 1). This area incorporates most of South America (and most of the Amazon basin), which is after all dominantly a tropical and Southern Hemisphere continent. This region is highlighted, because it lies largely within the influence of the South American summer monsoon (SASM), the largest and most significant climate feature of South America (Jones and Carvalho, 2013), a nearly continental-scale circulation that is responsible for much of the precipitation that falls from the Amazon River south to the La Plata Basin (Marengo et al., 2012a). The large changes in precipitation reconstructed on paleoclimate time scales throughout this domain are products of temporal changes in SASM intensity that are likely extrinsically forced by temporally variable insolation, greenhouse gas concentrations, glacial boundary conditions, and remote ocean–atmosphere interactions. The central questions of this review are: what is the history of the SASM and these extrinsic forcings?

Paleoclimate scientists are limited to proxy measurements that are imperfect recorders of a small number of climate variables in relatively few sites. However, in most of the tropics, including tropical South America, the instrumental record is itself limited by being short, sparse, incomplete, and imperfect. For example, Manaus is the only station in the entire Amazon basin having a century of weather data. A major issue is that this short and sparse instrumental record cannot capture low-frequency and long-term variation, therefore it records a relatively narrow amplitude of variation that neither fully characterizes the recent past nor the likely near future. Thus, we believe that lessons learned from studying the paleoclimate record of tropical South America provide insight into both past and future climates.

2. Modern climate of tropical South America and its relevance to the interpretation of Quaternary climate

The dynamics of past climates cannot be fully understood by simply extending what has been observed during the instrumental period, because most of the climate signals that are reconstructed from paleoclimate archives were of greater amplitude, longer duration, larger spatial footprint, and lower frequency than any that have been observed in the instrumental period. Thus, it is possible, even likely, that the origins of climate variation on “paleoclimate” time scales also were different than any that have been directly observed. Here we offer our own observations about both the importance, but also the limitations, of studies of modern climate variability as a means for deducing the origins and mechanisms of

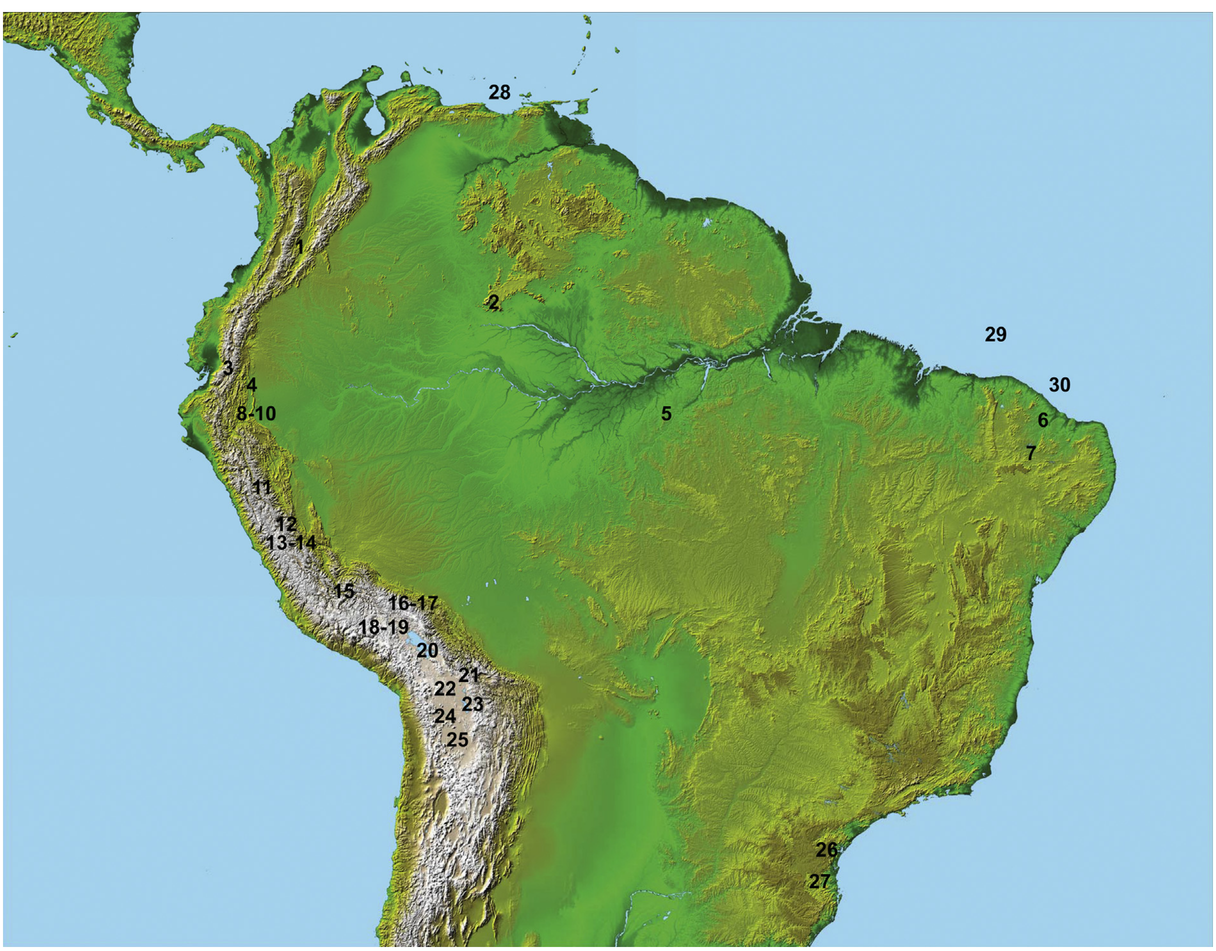

Fig. 1. Map of tropical South America showing the location of sites discussed in the text. See Table 1 for additional site information.