Quaternary Science Reviews 76 (2013) 29–38

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Rainfall response to orbital and millennial forcing in northern Peru over the last 18 ka

Elfi Mollier-Vogel [a,*], Guillaume Leduc [a], Tebke Böschen [b], Philippe Martinez [c], Ralph R. Schneider [a]

[a] Institute of Geosciences, University of Kiel, Germany
[b] GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
[c] Université Bordeaux 1, UMR CNRS 5805 EPOC, avenue des facultés, 33405 Talence Cedex, France

A R T I C L E I N F O

Article history:
Received 1 June 2012
Received in revised form
21 June 2013
Accepted 24 June 2013
Available online 16 July 2013

Keywords:
ITCZ
Speleothem
XRF
Holocene
Deglaciation
Younger Dryas
Heinrich 1

A B S T R A C T

We present a high-resolution marine record of sediment input from the Guayas River, Ecuador, that reflects changes in precipitation along western equatorial South America during the last 18ka. We use log (Ti/Ca) derived from X-ray Fluorescence (XRF) to document terrigenous input from riverine runoff that integrates rainfall from the Guayas River catchment. We find that rainfall-induced riverine runoff has increased during the Holocene and decreased during the last deglaciation. Superimposed on those long-term trends, we find that rainfall was probably slightly increased during the Younger Dryas, while the Heinrich event 1 was marked by an extreme load of terrigenous input, probably reflecting one of the wettest period over the time interval studied. When we compare our results to other Deglacial to Holocene rainfall records located across the tropical South American continent, different modes of variability become apparent. The records of rainfall variability imply that changes in the hydrological cycle at orbital and sub-orbital timescales were different from western to eastern South America. Orbital forcing caused an antiphase behavior in rainfall trends between eastern and western equatorial South America. In contrast, millennial-scale rainfall changes, remotely connected to the North Atlantic climate variability, led to homogenously wetter conditions over eastern and western equatorial South America during North Atlantic cold spells. These results may provide helpful diagnostics for testing the regional rainfall sensitivity in climate models and help to refine rainfall projections in South America for the next century.

1. Introduction

Seasonal and interannual rainfall variability in western equatorial South America is driven by a multitude of climatic processes, with the complex regional patterns additionally shaped by orography. On the Amazonian side of the equatorial Andes, high precipitation rates are found throughout the year, with maxima occurring at the equinoxes (Poveda et al., 2006; Garreaud et al., 2009; Fig. 1a). On the Pacific side, the orogenic barrier of the Andes blocks moisture transport from the Atlantic Ocean, making the Ecuadorian and Peruvian lowlands much drier than on the eastern side of the Andes. Still, there is a well defined subdivision between coastal regions located north and south of the equator which are affected by opposite seasonality in rainfall regimes (Poveda et al., 2006; Garreaud et al., 2009; Fig. 1a). In addition, interannual rainfall variability associated with the El Niño-Southern Oscillation (ENSO) contributes to the rainfall pattern complexity over South America (Dai and Wigley, 2000; Fig. 1b). Since the importance of these factors for regional rainfall patterns is difficult to assess, it remains problematic to understand the sensitivity of the hydrological cycle over South America to the climatic forcing at different timescales.

Beyond historical rainfall records, valuable information can be gained from paleoclimatic archives spanning time windows over which different forcings were at play. Past shifts in rainfall over South America since the Last Glacial Maximum (LGM) are thought to depend on, both, changes in orbital parameters and in the Atlantic Meridional Overturning Circulation (AMOC) intensity (Cruz et al., 2005; Wang et al., 2007). Changes in summer rainfall intensity are characterized by a latitudinal antiphase behavior between northern and southern tropics (Haug et al., 2001; Cruz et al., 2005; Wang et al., 2007). At the orbital timescale, a maximum in boreal summer insolation during the early Holocene triggered intense rainfall in northern South America, followed by a progressive aridification associated with the austral summer insolation increase during the mid- to late

* Corresponding author.
E-mail address: mollierv@gpi.uni-kiel.de (E. Mollier-Vogel).

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http://dx.doi.org/10.1016/j.quascirev.2013.06.021

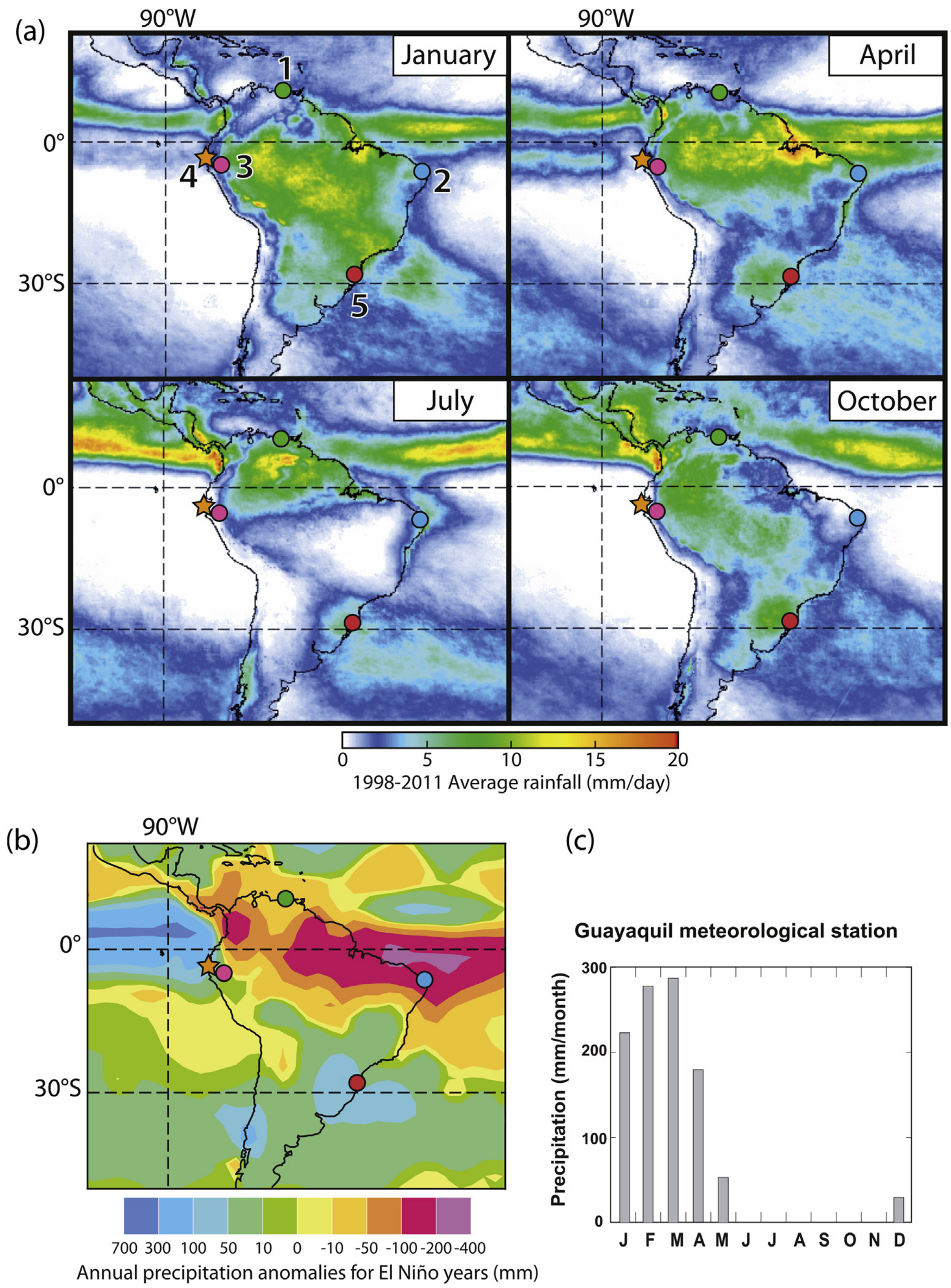

Fig. 1. (a) Seasonal changes in mean precipitation over South America derived from the Tropical Rainfall Measuring Mission (TRMM). Data extracted from the NASA/GSFC website available at http://trmm.gsfc.nasa.gov/. Location of paleo-precipitation records displayed in Fig. 5 are numbered as following: (1) Haug et al. (2001); (2) Cruz et al. (2009); (3) van Breukelen et al. (2008); (4) This study; (5) Wang et al. (2007). (b) Annual precipitation anomalies over South America for typical El Niño (modified from Dai and Wigley, 2000). (c) Mean monthly precipitation at Guayaquil, modified from Rincón-MartÌnez et al. (2010).

Holocene (Haug et al., 2001). In contrast, the southern tropics experienced drier conditions during the early to mid-Holocene, followed by wet conditions during the late Holocene as recorded in speleothems from southern Brazil (Cruz et al., 2005; Wang et al., 2007) and Andean lakes (Baker et al., 2001; Bird et al., 2011).

Closer to the equator, where the sun passes twice at zenith each year, the regional pattern of rainfall variability seems to be more complex than the simple antiphase behavior observed north and south of the equator where dry and wet seasons are well defined. Speleothem records collected close to the equator at the eastern and western edges of the Amazonian Basin indicate that Holocene changes in insolation have triggered an East–West antiphase in rainfall trends (Cruz et al., 2009). During the mid Holocene in particular, Northeastern Brazil was associated with wetter conditions than nowadays South of the equator (Cruz et al., 2009), while the western equatorial South America was marked by drier conditions (van Breukelen et al., 2008).

At the millennial timescale, a slowdown in AMOC associated with North Atlantic cold spells such as the Heinrich event 1 (H1) and the Younger Dryas (YD) induced a southward shift in rainfall over northern South America (Peterson et al., 2000; Haug et al., 2001; Leduc et al., 2007). Similar to the case for orbital forcing, the southern