Past Climate Variability in South America and Surrounding Regions

From the Last Glacial Maximum to the Holocene

Volume 14

Edited by
FrançoiseVimeux, Florence Sylvestre
and Myriam Khodri

Springer

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VOLUME 14

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ISBN 978-90-481-2671-2 e-ISBN 978-90-481-2672-9
DOI 10.1007/978-90-481-2672-9

Library of Congress Control Number: 2009926893

Cover illustration: Full disk image pair centered on South America. The images were made from a combination of AVHRR, NDVI, Seawifs, MODIS, NCEP, DMSP and Sky2000 catalog data, Photo credit: Image courtesy Nasa

Printed on acid-free paper

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Acknowledgments

We wish to thank all of the contributing authors. We are very pleased with the outcome of this book and we hope that the authors are as proud as we are.

All chapters benefited from a peer-review process. We would like to thank all the referees that dedicated time and efforts to make this book a valuable reference:

Mark Abbott, Emmanuel Chapron, John Chiang, Benjamin Lintner, Francisco Cruz, Valerio de Patta Pilar, Ricardo de Pol-Holz, Christine Delire, Laurent Dezileau, René Garreaud, Dominique Genty, William Gosling, Martin Grosjean, Simon Haberle, Henry Hooghiemstra, Vincent Jomelli, Meredith Kelly, Zhengyu Liu, Bryan Mark, Valérie Masson-Delmotte, Sarah Metcalfe, Christa Placzek, Antje Schwalb, Daniel Sigman, Christine Vallet-Coulomb, Mathias Vuille, Cathy Whitlock, Martin Williams.

Preface

South America is a unique place where a number of past climate archives are available from tropical to high latitude regions. It thus offers a unique opportunity to explore past climate variability along a latitudinal transect from the Equator to Polar regions and to study climate teleconnections. Most climate records from tropical and subtropical South America for the past 20,000 years have been interpreted as local responses to shift in the mean position and intensity of the InterTropical Convergence Zone due to tropical and extratropical forcings or to changes in the South American Summer Monsoon. Further South, the role of the Southern Hemisphere westerly winds on global climate has been highly investigated with both paleodata and coupled climate models. However the regional response over South America during the last 20,000 years is much more variable from place to place than previously thought. The factors that govern the spatial patterns of variability on millennial scale resolution are still to be understood.

The question of past natural rates and ranges of climate conditions over South America is therefore of special relevance in this context since today millions of people live under climates where any changes in monsoon rainfall can lead to catastrophic consequences.

We thus propose contributions that deal with tropical, temperate and high latitudes climate variability in South America with different type of archives and proxies on various timescales from the Last Glacial Maximum to the last thousand years. South America also offers a unique opportunity to examine climate fluctuations at various altitudes. The originality of this work is that it offers both observations and modelling works: we present contributions that aim at documenting paleoclimate histories and modelling studies are also included to help shed light on the relevant processes.

This book stems out from a 2006 Fall meeting American Geophysical Union (San Francisco, USA) session dealing with both overview and original researches on *Past climate variability from the last glacial maximum to the Holocene in South America and surrounding regions*. The 16 chapters in this volume are organized into three major parts. Part I, including 6 chapters, attempts at drawing a consistent picture for the Last Glacial Maximum in South America. Part II contains 4 chapters dealing with modern and past tropical and extra-tropical teleconnections with South America relying on both models and low to high latitudes ice core data comparison.

The third part of this book, containing the last 6 chapters, describes some aspects of the Holocene climate variability and specifically the southernmost part of South America which has been the subject of a growing attention during the recent years.

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Chapter 1
Moisture Pattern During the Last Glacial Maximum in South America

Florence Sylvestre

Abstract The Last Glacial Maximum (LGM) is still an exciting period of time for investigating ecosystem responses to climate changes since it corresponds to a steady state in a glacial world with maximum global expansion of ice-sheets, CO_2 concentrations half those of today, temperatures up to 5°C cooler in the tropical lowlands, and precipitation regimes differed from today. South America is an ideal place to study these changes since climatic conditions during the LGM remain a matter of debate. There is general agreement that the temperature was cooler than today, but there is no consensus about moisture conditions, especially over tropical latitudes. This paper reviews terrestrial and near-shore marine records from South America between 10°N and 50°S during the LGM. Records are selected for their chronological control, their continuity around the LGM and their regional representativeness.

This review aims to show how regional climates of the sub-continent have responded to orbital forcing as opposed to other global glacial boundary conditions, and how they are related to positions of the Intertropical Convergence Zone (ITCZ) and of the westerly belt. A clear pattern emerges for the northern and the southern latitudes, which were respectively drier and wetter, but in the tropical lowlands the pattern remains unclear. The characterization of this area is of particular interest because of the central role played by atmospheric convection centred on the Amazon basin. Modeling experiments argue for drier LGM tropical conditions but several lines of evidence contradict these results. Currently, moister conditions are explained by a glacial boundary forcing mechanism implying a southern shift of the ITCZ and a reinforcement of the South American summer monsoon (SASM), bringing more humidity to the tropical Andes as far as southern Brazil. This hypothesis may explain a large portion of the ecosystem responses during the LGM, but does not account for all observed changes. Paucity of site reconstructions (e.g. in the Amazon basin), and lack of quantitative paleoclimatic responses derived

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F. Vimeux et al. (eds.), *Past Climate Variability in South America and Surrounding Regions*, Developments in Paleoenvironmental Research 14,
DOI 10.1007/978-90-481-2672-9_1,

from proxies to environmental conditions could partly explain the observed discrepancies. Regional responses of mosaic environmental ecosystems to a generally cooler temperature could be involved, without any need to invoke precessionnal and extra-tropical influences.

Keywords South America · Last Glacial Maximum (LGM) · Paleoclimates · Moisture pattern

1.1 Introduction

Since the international CLIMAP project (1981), a general consensus exists that the Last Glacial Maximum (LGM) climate was much colder, and for the most part, more arid than today. Currently available evidence suggests that intertropical areas probably cooled by 1–3°C in the surface ocean, and by about 4–6°C at moderate altitude on the continents (COHMAP 1988). Since then, from data and models, there is agreement that the tropics were cooler during the LGM, even if the magnitude of the cooling is not spatially uniform. For instance, Central America and northern South America cooled by 5–6°C, whereas regions peripheral to the Indian Ocean (southern and eastern Africa, India and Indonesia) cooled by 2–3°C (Farrera et al. 1999). Coupled atmosphere-ocean-sea-ice simulations suggest that the tropics and subtropics were considerably drier at the LGM than today (Shin et al. 2003). However, several paleoclimatic reconstructions based on proxy data contradict these findings and for several areas, moisture conditions remain a matter of debate. South America illustrates particularly this feature where climate conditions during the LGM are still highly documented by proxy data (Wang et al. 2004; Ledru et al. 2005; Cruz et al. 2005, 2006a, b; Wang et al. 2006; Fritz et al. 2007; Hodell et al. 2008), and investigated by both GCMs coupled and atmosphere-only versions (Shin et al. 2003; Wainer et al. 2005), and regional climate model (Cook and Vizy 2006; Vizy and Cook 2007).

Through this debate, the main question investigated by paleoclimatologists concerns the preferred location of the marine Atlantic Intertropical Convergence Zone (ITCZ) and the continental convection over the Amazon basin. In 1997, Bradbury commented that "to account for dry conditions during full and late glacial periods, the ITCZ is supposed to have resided farther north by South American workers (Martin et al. 1997) and farther south by North American workers". More recently, Ti/Fe records off the coast of Venezuela showed the role of the North Atlantic sea surface temperature at millennial and orbital time-scales on the tropical hydrologic cycle (Peterson et al. 2000; Haug et al. 2001). This study suggests that a southerly mean position coincided with cooler north Atlantic sea surface temperature and reduced precipitation in the northern tropics; whereas during warm periods, the northern tropics were wetter and associated with weakened wind strength and a more northerly ITCZ position (Peterson et al. 2000; Peterson and Haug 2006). The reverse pattern is observed in the southern hemisphere tropics (Arz et al. 1998; Jennerjahn et al. 2004; Wang et al. 2004; Jaeschke et al. 2007). Both atmospheric general circulation models (AGCMs) alone or coupled to a slab ocean explored these observations and suggested that the expansion or contraction of land- and sea-ice during the LGM or during millennial events can lead to a displacement of the ITCZ and produce precipitation asymmetries over tropical latitudes (Chiang et al. 2003; Claussen et al. 2003; Chiang and Bitz 2005).

Moreover this hypothesis dealing with the glacial boundary forcing is not exclusive from others mechanisms. Although less drastic than in the North (Petit et al. 1999; Alley 2004), cooling in Southern Hemisphere high latitudes has also played a central role in global climatic changes during the last glacial period. Model simulations suggest that the expansion of circum-Antarctic sea-ice has had a much stronger influence than Northern Hemisphere sea-ice, possibly because of its far greater areal extent (Chiang et al. 2003; Chiang and Bitz 2005). Antarctic sea-ice expansion reinforces the southern hemisphere meridional temperature gradients and forces the southern hemisphere oceanic and atmospheric frontal zones to move equatorward (Stuut et al. 2004; Stuut and Lamy 2004). Mechanisms originated from the tropics could also exert an influence on the climate. Variability in the precession-driven monsoon intensity (Ivanochko et al. 2005), tropical sea-surface temperatures (Visser et al. 2003), methane emission in tropical wetlands (Chappellaz et al. 1993; Severinghaus et al. 1998) and El Niño-Southern Oscillation (ENSO) mechanism (Cane 2005) may have had significant effects in high latitudes.

Testing these hypotheses for continental South America during the LGM is of particular interest. The LGM is defined by the lowest sea level and maximum ice volume (Mix et al. 2001). This time period has been the theatre of considerable debate for continental South America, especially for the tropical latitudes where moisture patterns showed distinct regional differences (Sylvestre et al. 1998; Baker et al. 2001a, b; Sylvestre 2002; Ledru et al. 2005; Smith et al. 2005a; Wang et al. 2006; Cruz et al. 2006a, b; Fritz et al. 2007; Hodell et al. 2008). Moreover, climatologists increased our knowledge about the present-day climate system of South America, describing the seasonal cycle of precipitation dominated by the South American Monsoon (SASM), its interannual variability and the remote forcing mechanisms acting over the system giving to the paleoclimatologists some keys for understanding the climatic changes at different time-scales during the past (Lenters and Cook 1997; Nogués-Paegle et al. 2002; Garreaud et al. 2003; Cook and Vizy 2006; Vera et al. 2006; Vizy and Cook 2007; Garreaud et al. in press; Cook, Chapter 8 of this volume).

The objectives of this paper are to review the best-dated terrestrial and near-shore marine paleoclimatic records from South America during the LGM. A detailed description of individual records is beyond the scope of this paper. The present review aims at highlighting the moisture pattern emerging from a set of well-dated sites representative of the main climatic regions of the continent. This review investigates a variety of terrestrial archives (pollen data, lake sediments and shorelines, speleothems and cores deposits, fluvial, periglacial and glacial deposits), as well as ice and near-shore marine cores. Records are selected for their chronological control, their continuity around the LGM and their regional representativeness. The reconstructions cannot provide accurate quantitative information about changes in the magnitude or seasonality of rainfall. In most case studies, they offer observation-based evidence about whether the past climate was wetter or drier than the present day. This review is organized around the regions defined by their moisture sources. Throughout this manuscript, all ages are given in calendar ages, using Calib 5.01 (Reimer et al. 2004) or the polynomial equations of Bard et al. (1998) when original references provide ^{14}C ages. This review proceeds as follows. Section 1.2 summarizes the major contemporary climate features of South America. Figure 1.1 presents the modern settings of the South American continent summarizing the major features of the climatic system. This figure also shows the selected sites cited in the text, called S1, S2..., and listed in Table 1.1 with their main characteristics. Section 1.3 presents evidence for regional paleoclimate changes during the LGM, and discusses discrepancies, if any, between records of proxies. Figure 1.2 shows the main paleoclimatic characteristics of each selected sites, interpreted as wetter or drier conditions than today and summarizes the major paleoclimatic forcing mechanisms discussed in the following section. Section 1.4 identifies recent progress and unresolved questions about key paleoclimatic issues.

1.2 Modern Climate

By its continental mass extension across the equator from about 10°N to 55°S, South America displays a large distribution from tropical to extratropical climates. This distribution is defined by several regional and remote factors, in primary order the shape and the topography of the continent (e.g. the Andes mountains, the Amazon rain forest). Its vicinity to the surroundings oceans and its relationships between sea surface temperature (SST) anomalies in association with El Nino/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the Antarctic Annular Modes, or the North Atlantic oscillation (NAO) constitute also significant impacts on the climatic variability over the continent (Garreaud et al. in press).

Today, the seasonal precipitation cycle over South America is dominated in tropical latitudes by a monsoon-like system, the South American Summer Monsoon (SASM) (Zhou and Lau 1998; Barros et al. 2002; Nogués-Paegle et al. 2002; Vera et al. 2006) which involved two main components: (i) a near equatorial one associated with the Atlantic Convergence Zone (ITCZ) and convection over Amazonia, and (ii) a subtropical one associated with the South Atlantic Convergence Zone (SACZ) and related features over southeast South America (30/32°S) (Fig. 1.1). These features are connecting through a large-scale atmospheric circulation comprising a low-level jet (Vera et al. 2006). This low-level jet (LLJ) originating in the northern part of South America at the foot of the Andes, is driven by the Chaco Low to provide moisture for subtropical latitudes (Nogués-Paegle and Mo 1997; Labraga et al. 2000). Over that region, the seasonal development of the SACZ results of the confluence of the low-level jet moisture transport with the northeasterly winds coming from the South Atlantic High and the mid-latitude westerly flow on the southern boundary of the South Atlantic High (Saulo et al. 2000). Nogués-Paegle