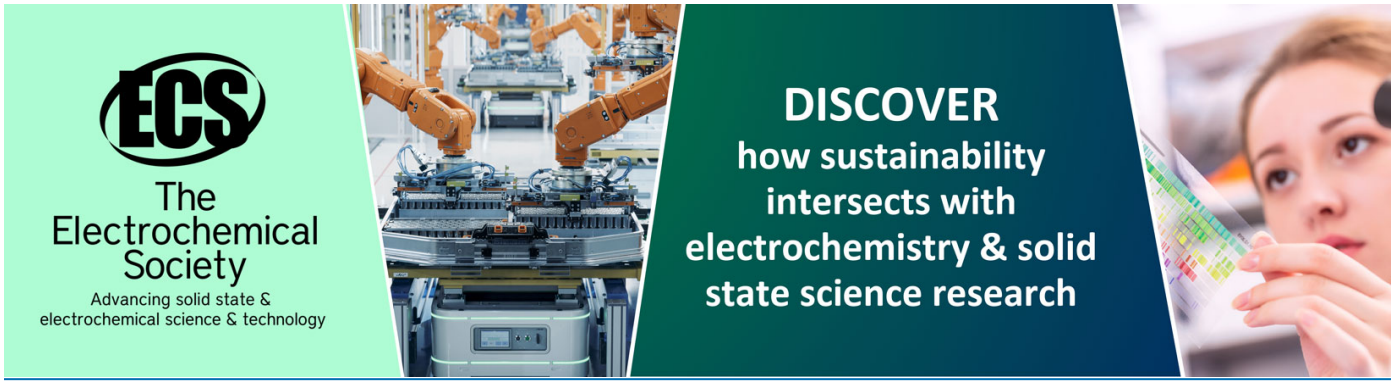
How different proxies record precipitation variability over southeastern South America



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How different proxies record precipitation variability over southeastern South America

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Abstract. Detrending natural and anthropogenic components of climate variability is arguably an issue of utmost importance to society. To accomplish this issue, one must rely on a comprehensive understanding of the natural variability of the climate system on a regional level. Here we explore how different proxies (e.g., stalagmite oxygen isotopic composition, pollen percentages, bulk sediment elemental ratios) record Holocene precipitation variability over southeastern South America. We found a general good agreement between the different records both on orbital and centennial time-scales. Dry mid Holocene, and wet late Holocene, Younger Dryas and a period between ~9.4 and 8.12 cal kyr BP seem to be pervasive features. Moreover, we show that proxy-specific sensitivity can greatly improve past precipitation reconstructions.

1. Introduction

Southeastern South America (SESA) is the most densely populated, industrialized and agriculturally productive region in the continent. Domestic, industrial and agricultural water and power supply strongly relies on seasonal precipitation associated with the South American summer monsoon (SASM). Thus, hydrological changes are of great concern in the context of anthropogenic climate change. Assessing past changes in precipitation has the potential to clarify the mechanisms that govern precipitation under different boundary conditions. Here we present bulk sediment elemental ratios (Al/Si) reflecting changes in Holocene chemical weathering in SESA and compare this record with charcoal accumulation rates, stalagmite oxygen isotopic composition ($\delta^{18}O$), and pollen percentages in order to explore how different proxies record precipitation variability over SESA.

2. Environmental setting and methods

2.1. Environmental setting

Precipitation over SESA is mainly related to the southward expansion and intensification of the SASM, while austral winter rainfall associated with mid-latitude cyclonic activity over the South Atlantic plays a secondary role (figure 1) [1, 2]. During austral summer, Amazon moisture is

transported southwards by the South American low level jet, producing strong precipitation in the South Atlantic convergence zone (SACZ) [3]. During austral winter, incursions of mid-latitude air masses into the southern SESA associated with episodes of enhanced cyclonic activity over the South Atlantic generate winter rainfall that progress northwards along the Atlantic coast [2]. Interannual variability in precipitation over SESA has been related to El Niño-Southern Oscillation (i.e., El Niño is associated with above-normal precipitation) whereas interdecadal changes were associated to sea surface temperature (SST) fluctuations in the western South Atlantic (i.e., positive SST anomalies were associated with above-normal precipitation) [4].

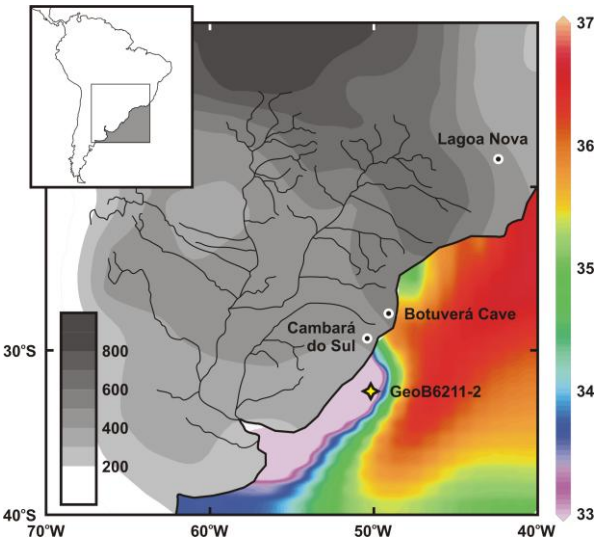

Figure 1. Location of sites GeoB6211-2 (this study) in the western South Atlantic, and Lagoa Nova [12], Botuverá Cave [14, 15] and Cambará do Sul [18] in southeastern South America. Color shading shows long-term mean annual sea surface salinity (in psu) [27], and grey shading shows long-term mean December-February precipitation (in mm) [28]. The main tributaries of the La Plata River drainage basin are also shown.

2.2. Methods

Our Al/Si record was obtained from marine sediment core GeoB6211-2 (32.50°S, 50.24°W, 657 m water depth) (figure 1). We focused on the last 14 cal kyr BP where we found relatively constant sedimentation rates (~9cm kyr^{-1}). Details of GeoB6211-2 calibrated ^{14}C-based age model are provided in Chiessi et al. [5]. Aluminum and Si intensities were determined in bulk sediment using X-ray fluorescence (XRF) core scanner. Prior and after analysis, the instrument was calibrated against a set of pressed powder standards. Further methodological details can be found in Chiessi et al. [6].

Considering that the eolian input [7] and the biogenic opal accumulation rate [8] in our core site is relatively small, we interpret the Al/Si ratio in GeoB6211-2 as an indicator of the intensity of chemical weathering in the La Plata River drainage basin (PRDB) (figure 1), related to precipitation variability over the basin. The PRDB is the fifth largest river basin in the world, extending over 3.1 million km^2, and draining a significant portion of the SASM precipitation. Depetris et al. [9] and Depetris and Pasquini [10] showed that the Al/Si ratio in the suspended sediment load of the PRDB northwestern tributaries is significantly lower than the same ratio for the northeastern tributaries. The authors associated this difference to the less (more) intense chemical weathering conditions in the northwestern (northeastern) sector of the basin, largely controlled by the present-day distribution in precipitation.

3. Results

Our Al/Si record shows centennial-scale fluctuations superimposed on a long-term trend of decreasing values (0.03) from 14 until ~6.25 cal kyr BP, and increasing values (0.07) from 6.25 cal kyr BP until the present (figure 2e). Maximum and minimum values are 0.32 and 0.21, respectively. A peak with relatively low amplitude is observed between 12.62 and 11.52 cal kyr BP, whereas a peak with relatively high amplitude appears between ~9.4 and 8.12 cal kyr BP. Two discrete increases in the Al/Si ratio are present around 4.52 and 2.36 cal kyr BP.

4. Discussion

Charcoal accumulation rates in continental sediments can be considered an index of the overall fire frequency, intensity and extent of the regional fire regime [11]. While the incidence of fire over space and time is influenced by complex interactions between climate, fuels, and ignition, the Lagoa Nova record (figures 1 and 2a) was interpreted to mainly reflect climate conditions around the sampling site [12]. Fire frequency was relatively high between ~11 and 9.5 cal kyr BP, and between ~8.5 and 7 cal kyr BP. From ~7 cal kyr BP towards the present, fire frequency decreased gradually. Together with palynological evidence from the same site, the author assigned a long dry season of about 6 months and annual precipitation lower than today for the two periods of high fire frequency. On the other hand, the intermediate period of low fire frequency as well as the mid and late Holocene showed wetter climatic conditions with an annual dry season of about 4 months.

The variability in $\delta^{18}O$ of tropical and subtropical stalagmites depends on temperature, the amount effect, and the moisture source [13]. Oxygen isotopic composition of Botuverá Cave stalagmites (figures 1 and 2b) has been mainly related to changes in the moisture source [14, 15]. Early and mid Holocene $\delta^{18}O$ values are relatively high and were associated to South Atlantic extratropical moisture, whereas late Holocene low $\delta^{18}O$ values are typical of Amazon-derived moisture. A sharp peak characterized by low values was observed to coincide with the Younger Dryas (YD) (~12.85-11.7 cal kyr BP [16]). Thus, the moisture source feeding precipitation over Botuverá Cave closely followed changes in austral summer insolation at subtropical latitudes (figure 2f) but also varied on shorter time-scales reflecting abrupt shifts in atmospheric circulation related to changes in the Atlantic meridional overturning circulation (AMOC) [14, 15].

Some plant taxa are particularly sensitive to climate conditions, and in the case of good preservation of their palynomorphs may constitute important proxies for past climate. A good example is the tree *Araucaria angustifolia*, typical of southern Brazilian forests, that requires a minimum of 1400 mm annual rainfall without a marked annual dry season [17]. Moreover, shifts in grassland/forest boundaries in SESA are an important tool for reconstructing past climates [17]. The herb family Poaceae is one of the main representatives of SESA grasslands and temporal changes in its relative abundance in site Cambará do Sul (figure 1) are depicted in figure 2c together with temporal changes in the relative abundance of *A. angustifolia* [18]. Increasing percentages of Poaceae through the early and mid Holocene together with constant values of *A. angustifolia* suggest a trend towards drier conditions with a long annual dry season. After ~5 cal kyr BP, an increase in *A. angustifolia* and a decrease in Poaceae abundances points to a gradual humidification until ~1 cal kyr BP when the forest biome replaced grasslands, reflecting the onset of the wettest period in the last 14 cal kyr BP with no marked annual dry season.

Long-term changes in chemical weathering in the PRDB as recorded by GeoB6211-2 (figure 1) Al/Si ratios (figure 2e) followed subtropical austral summer insolation (figure 2f). A similar orbital-scale trend is observed in Botuverá Cave $\delta^{18}O$ values and in Cambará do Sul Poaceae abundances. The common signal corroborate model simulations pointing to a decrease in moisture transport from the Amazon basin to SESA, and a reduced intensity of the SACZ during the mid Holocene in relation to present-day climate [19]. Low (high) peak austral summer insolation during the mid Holocene (late glacial and late Holocene) would be responsible for the observed pattern by shifting the mean position of the Intertropical Convergence Zone (ITCZ) to the north (south) and affecting the SASM circulation (e.g., South American low level jet, SACZ) [14]. Because the relative abundances of *A. angustifolia* do not show high values for the late glacial and the early Holocene, we assume the occurrence of a relatively long annual dry season despite of the relatively high total annual rainfall for that period.

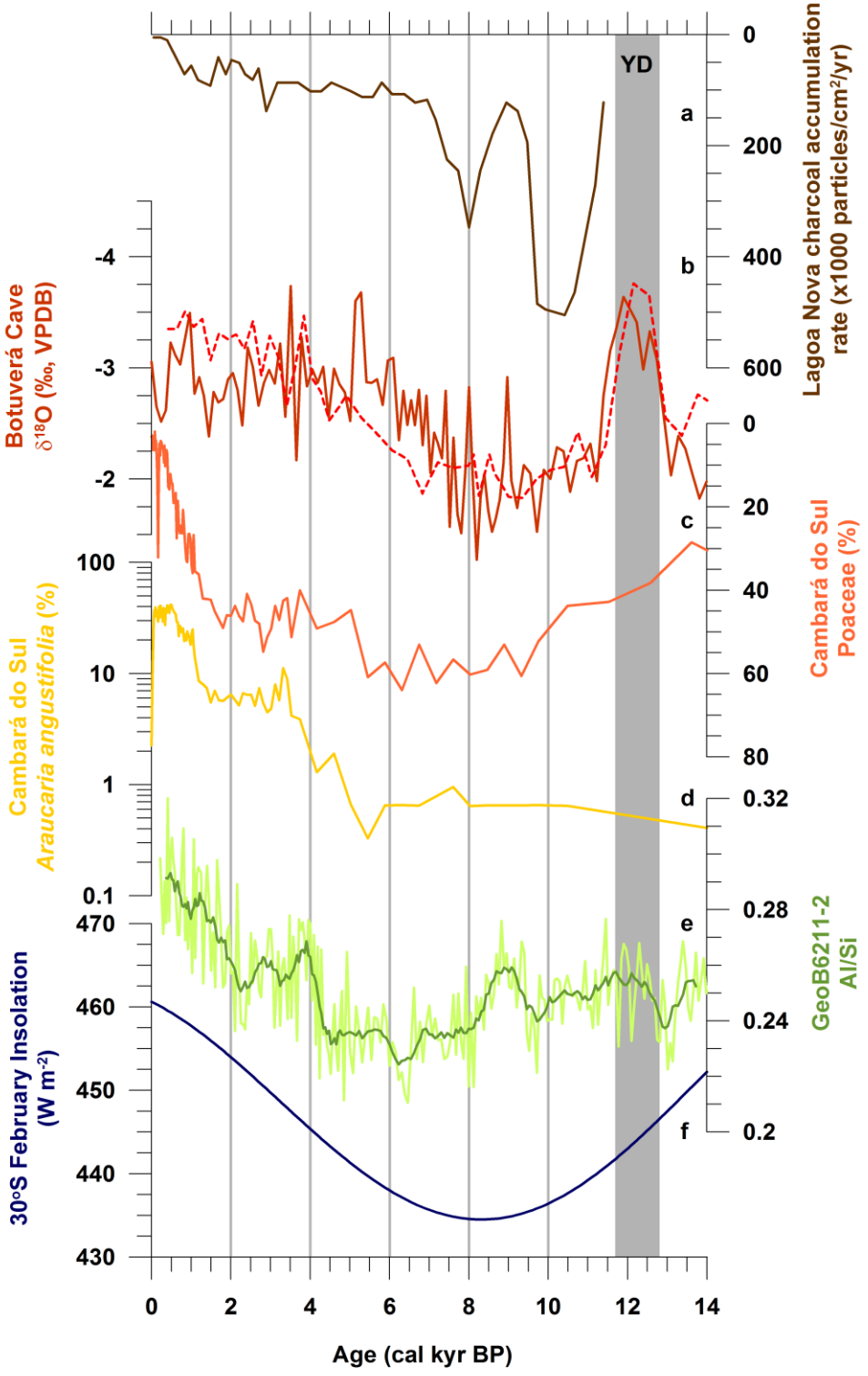

Figure 2. Proxy records of precipitation variability over southeastern South America compared to subtropical austral summer insolation. **a** Lagoa Nova [12], **b** Botuverá Cave (bold line Cruz et al. [14] with age model of Cruz et al. [29], dashed line Wang et al. [15]), **c** and **d** Cambará do Sul [18], **e** GeoB6211-2 raw data (pale green line) and 9 point moving average (green line) (this study), and **f** Berger and Loutre [30]. All proxy curves show more humid conditions towards the top of the panel. Note the reverse scale in **a**, **b** and **c**. The grey bar shows the duration of the Younger Dryas (YD) [16].

Centennial-scale changes in the Al/Si record are also present in other paleoprecipitation records from SESA when the necessary temporal resolution is available. The low amplitude peak around 12 cal kyr BP has a counterpart in the Botuverá Cave $\delta^{18}O$ record, while the much stronger peak between ~9.4 and 8.12 cal kyr BP is clearly related to a decrease in charcoal accumulation rate in the Lagoa Nova record. A major slowdown event in AMOC strength happened during the YD [20] and was claimed to affect atmospheric circulation in SESA [14, 15]. As summarized by Chiessi et al. [6], periods of weak AMOC are related to anomalously warm SSTs in the South Atlantic [21, 22] and increased SACZ activity, displacing the main belt of SASM precipitation to the south. Amplified SACZ activity would increase rainfall over the PRDB, the intensity of chemical weathering in the basin and the Al/Si ratio of the basin's suspended sediment load. Another mechanism linking AMOC strength and SASM/SACZ involves the position of the ITCZ. Modeling results show that during periods of weak AMOC the ITCZ is shifted to the south causing a positive anomaly in moisture transport into the Amazon basin [23]. The equatorial anomalies would enhance convection in the Amazon basin, reinforcing moisture transport towards SESA during austral summer (i.e., SASM/SACZ) [3].

The peak between ~9.4 and 8.12 cal kyr BP is too long to be related to the sudden 8.2 kyr event, but could be indeed associated to a multi-century climate change reported in many monsoon areas around the globe [24]. In this case, it would be part of a repeating pattern of longer-term anomalies during the Holocene, with its most recent manifestation during the Little Ice Age. It is noteworthy that the peak of high precipitation in the PRDB between ~9.4 and 8.12 cal kyr BP is remarkably synchronous to high levels in Lake Titicaca [25] and to an early peak in human occupation in central Brazil [26].

5. Conclusions

We found a general good agreement between different proxies (e.g., stalagmite $\delta^{18}O$, pollen percentages, and bulk sediment elemental ratios) recording precipitation variability over SESA. While most of them show an austral summer insolation-driven long-term variability with a dry mid Holocene and a wet late Holocene, records with high temporal resolution depict centennial-scale changes that seems to be pervasive (e.g., a wet YD). We conclude that proxy-specific sensitivity (e.g., the ability to distinguish different moisture sources in stalagmite $\delta^{18}O$, the duration of the dry season in *A. angustifolia*, and the basin integrated precipitation in bulk sediment elemental ratios) should be used in order to draw a more complete scenario of paleoprecipitation variability.

Acknowledgments

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References

[1] Zhou J and Lau K –M 1998 *J. Clim*. **11** 1020
[2] Vera C S, Vigliarolo P K and Berbery E H 2002*Mon. Weather Rev.* **130** 684
[3] Marengo J A, Soares W R, Saulo C and Nicolini M 2004 *J. Clim.* **17** 2261
[4] Robertson A W and Mechoso C R 2000 *Mon. Weather Rev.* **128** 2947
[5] Chiessi C M, Mulitza S, Paul A, Pätzold J, Groeneveld J and Wefer G 2008 *Geology* **36** 919
[6] Chiessi C M, Mulitza S, Pätzold J and Wefer G 2009 *Geophys. Res. Lett.* **36** doi:10.1029/2009GL039914
[7] Mahowald N M, Muhs D R, Levis S, Rasch P J, Yoshioka M, Zender C S and Luo C 2006 *J. Geophys. Res.* **111** doi:10.1029/2005JD006653

[8] Romero O and Hensen C 2002 *Mar Geol* **186** 263
[9] Depetris P J, Probst J -L, Pasquini A I and Gaiero D M 2003 *Hydrol. Process*. **17** 1267
[10] Depetris P J and Pasquini A I 2007 *The Middle Paraná River: Limnology of a Subtropical Wetland* ed M H Iriondo et al. (Berlin, Springer-Verlag) p 143
[11] Power M J et al. 2008. *Clim. Dyn.* **30** 887
[12] Behling H 2003 *Veget. Hist. Archaeobot.* **12** 263
[13] Vuille M, Bradley R S, Werner M, Healy R and Keimig F 2003 *J. Geophys. Res.* **108** doi:10.1029/2001JD002038
[14] Cruz F W C, Burns S J, Karmann I, Sharp W D, Vuille M, Cardoso A O, Ferrari J A, Dias P L S and Viana O 2005 *Nature* **434** 63
[15] Wang X, Auler A S, Edwards R L, Cheng H, Ito E, Wang Y, Kong X and Solheid M 2007 *Geophys. Res. Lett*. **34** doi:10.1029/2007GL031149
[16] Rasmussen S O et al. 2006 *J. Geophys. Res*. **111** doi:10.1029/2005JD006079
[17] Behling H 2002 *Palaeogeogr Palaeocl* **177** 19
[18] Behling H, Pillar V D, Orlóci L, Bauermann S G 2004 *Palaeogeogr Palaeocl* **203** 277
[19] Melo M L D and Marengo J A 2008 *Holocene* **18** 501
[20] McManus J F, Francois R, Gherardi J -M, Keigwin L D and Brown-Leger S 2004 *Nature* **428** 834
[21] Arz H W, Pätzold J, Wefer G 1999 *Earth. Planet. Sc. Lett.* **167** 105
[22] Stouffer R J et al. 2006 *J. Climate* **19** 1365
[23] Zhang R and Delworth T L 2005 *J. Clim*. **18** 1853
[24] Rohling E J and Pälike H 2005 *Nature* **434** 975
[25] Baker P A, Seltzer G O, Fritz S C, Dunbar R B, Grove M J, Tapia P M, Cross R B, Rowe H D and Broda J P 2001 *Science* **291** 640
[26] Araujo A G M, Neves W A, Piló L B and Atui J P V 2005 *Quaternary Res.* **64** 298
[27] Conkright M E, Locarnini R A, Garcia H E, O'Brien T D, Boyer T P, Stephens C and Antonov J I 2002 World ocean atlas 2001: Objective analyses, data statistics, and figures CD-ROM documentation, *Internal Rep. 17*, Natl. Oceanogr. Data Cent., Silver Spring MD
[28] Xie P and Arkin P A 1997 *Bull. Am. Meteorol. Soc.* **78** 2539
[29] Cruz F W C et al. 2009 *Nature Geosci.* **2** 210
[30] Berger A and Loutre M F 1991 *Quat. Sci. Rev.* **10** 297