The coupling between monsoon rainfall and sea surface temperatures in the subtropical South Atlantic during the Last Glacial Period

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Abstract

Here, we display high-resolution trace element data from the Botuverá Cave (27°S) as a proxy for paleo-precipitation amount covering the Last Glacial Period. Our record highlights an in-phase variation between Mg/Ca, Sr/Ca, and $\delta^{18}O$ for the first two insolation cycles suggesting increased precipitation due to enhanced monsoon activity during high austral summer insolation. Furthermore, this comparison of speleothem records allows us to discuss the relationship between the monsoon circulation and variations in Sea Surface Temperature (SST) in the South Atlantic. In this regard, we compare the speleothem to marine SST records to identify feedback mechanisms between the atmosphere circulation and the South Atlantic. Two modes of precipitation variability are proposed: 1) from 115 to 55 kyrs, an in-phase precipitation variability between the areas affected by the South Atlantic Convergence Zone (SACZ) and the Andean Low-Level Jet (ALLJ) moisture trajectories; and 2) from 55 to 13 kyrs, a precipitation dipole is identified between SACZ and ALLJ monsoon domains.

1. Introduction

The speleothem isotope records from subtropical South America have revealed changes in rainfall regime during the Last Glacial Period as a response to the precession cycles and millennial climatic events. In southern-Brazil, the negative (positive) oxygen isotope ratios ($\delta^{18}O$) values in stalagmite-calcite reflect a higher amount of rainfall sourced from the Amazon (South Atlantic) regions in periods of enhanced (weakened) South America Monsoon System (SAMS), in phases of high (low) austral summer insolation (CRUZ et al., 2005). As for millennial events, negative $\delta^{18}O$ incursions are associated with temperature cooling and ice volume expansion in the North Atlantic (CRUZ et al., 2005; CRUZ et al., 2006; WANG et al., 2007). However, the effect of the seasonal changes in moisture source areas prevent a direct rainfall amount reconstruction based on of the speleothem $\delta^{18}O$ records. Furthermore, BAO et al. (2023a, 2023b) recently provided evidence, based on climate model simulations, indicating that $\delta^{18}O$ variations in speleothem records do not directly correspond to changes in local precipitation. Instead, these variations are primarily influenced by isotopic fractionation in the rainfall source regions, which is associated with changes in the intensity of convection within the Intertropical Convergence Zone (ITCZ). This evidence challenges the traditional interpretation of $\delta^{18}O$ in speleothems as a direct proxy for local hydroclimatic conditions and raises broader concerns about its reliability as a climate proxy.

The use of trace element ratios (E/Ca) as a proxy for local aquifer recharge made it possible to associate the moisture source area with changes in the annual average rainfall for paleoclimate interpretations from south-Brazil stalagmites during last glacial period and Holocene (CRUZ et al., 2007; BERNAL et al., 2016). The cave monitoring of drip water's Sr/Ca and Mg/Ca ratios in the region revealed that prior calcite precipitation (PCP) is the main mechanism responsible for the trace elements variation in the modern speleothems (KARMANN et al., 2007). The pioneer study based on Sr/Ca and Mg/Ca records by using electron microprobe technique in the Bt2 stalagmite from Botuverá cave indicated that lower (higher) Sr/Ca and Mg/Ca ratios correlate with phases of negative (positive) $\delta^{18}O$ values and high (low) summer austral insolation, corresponding to periods of increased (decreased) rainfall (CRUZ et al. 2007). This multiproxy approach also demonstrated that the period between 60 and 19 ky BP had an anomalous increase in local rainfall amount that is not well coupled with precession cycles but with the full glacial boundary conditions associated with cooler North Atlantic Ocean (CRUZ et al., 2007). However, this data lacks temporal resolution and presents high instrumental noise that inhibited precise interpretations of the millennial scale variability during the last glacial period. To date, a relationship has not yet been established between changes in the monsoon regime and the climatic conditions of the South Atlantic Ocean as observed in modern times. Addressing this gap is imperative given the emergence of new paleoceanographic reconstructions from the (sub)tropical South Atlantic, extending back to the Last Glacial Period.

Advancements in the use of LA-ICP-MS method (Laser Ablation-Ion Coupled Plasma-Mass Spectrometry) enabled data acquisition close to annual resolution even for stalagmites with low growth rates like Bt2, from Botuverá cave (BERNAL et al., 2016) among other speleothem records. BERNAL et al. (2016) used LA-ICP-MS data record from Botuverá to confirm the in-phase changes in trace element and isotopic data following the summer insolation curve during the Holocene. With the increased resolution of trace element data using LA-ICP-MS, it was possible to identify the climate response to broader discussed millennial scale events such as the 8.2 ky BP and Little Ice Age, which were undistinguishable in the lower-resolution δ18O curve. In this regard, the application of the same technique on a stalagmite covering the entire Last Glacial Period could offer a unique possibility to refine the interpretation of the δ18O during millennial scale events during the last glacial period by comparing with trace element data from the same speleothems.

The present work presents a high-resolution trace element record from LA-ICP-MS in the Bt2 stalagmite for the whole Last Glacial period. We aim to discuss variations in moisture source area and changes in local rainfall recharge amount on orbital and millennial timescales. The data also allows discussion of the relationship between monsoon continental isotope records and the sea surface temperature (SST) reconstructions from the South Atlantic, aiming to debate the influence of summer insolation and Atlantic meridional overturning circulation (AMOC) on the SAMS and the feedback between the SAMS and South Atlantic SSTs.

2. Materials and methods

Stalagmite Bt2 was collected from Botuverá cave (27°13'24"S; 49°09'20"W) (Fig. 1), southern Brazil. The stalagmite Bt2 speleothem record chronologically uses 33 $^{234}U/^{230}Th$ dates published by MILLO et al. (2017). It ranges from 2.78 to 113.47 ky BP, and all dates are in stratigraphic order without long hiatus and inversions. Most dates have an error (2σ) of under 1.0%. Speleothems from the Botuverá Cave present very slow growth that range between ~12 mm/ky BP and ~8 mm/ky BP. For this reason, the resolution of stable isotopes is relatively low. The new δ18O curve presented here has 879 samples. The oxygen isotope ratios are expressed in δ notation for carbonate speleothems, the per mil deviation from the Vienna Pee Dee Belemnite (VPDB) standard.

Trace element ratios were obtained by Laser-ablation ICP-MS using a Resonetics L-50 excimer laser-ablation workstation (ArF, λ=193 ns, 23ns FWHM, fluence of ~6 J/cm²) at Centro de Geociencias, Universidad Nacional Autónoma de México (UNAM), following methods described in BERNAL et al. (2016). The Bt2 trace element data presented in this work is a composite of normalized data from two different sections of the sample analyzed at different times (one in 2016 and the other in 2023) in the same laboratory and method constructed by the intra-site correlation model (ISCAM) (FOHLMEISTER, 2012).

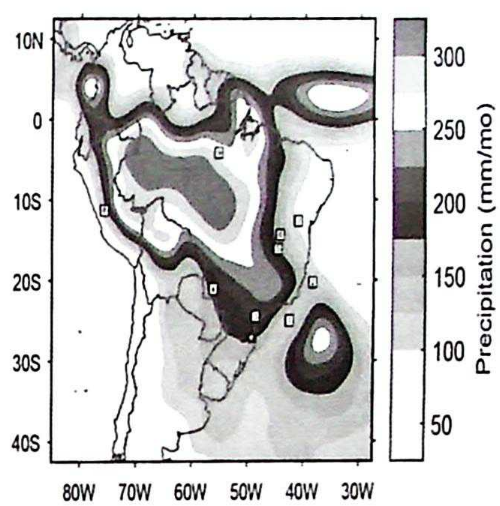

Figure 1: Location of records used for paleoclimatic comparisons. Botuverá cave (yellow star; data from this paper), 1: marine core GL-1090 (SANTOS et al., 2017; MATHIAS et al., 2021), 2: marine core M125-55-7 (HOU et al., 2020); 3: Santana cave (KARMANN et al., 2007); 4: Jaraguá cave (NOVELLO et al., 2017), 5: Lapa Sem Fim cave (STRIKIS et al., 2015), 6: Lapa Grande cave (STRIKIS et al., 2017), Paixão cave (STRIKIS et al., 2015), 8: Pacupahuain cave (KANNER et al., 2013), and 9: Paraíso cave (WANG et al., 2017).

3. Results

The Mg/Ca and Sr/Ca records from Bt2 consist of nearly 173,000 points, resulting in a sub-annual resolution. The values presented throughout this work were reduced using a 50-point running means to improve data visualization. Advances in the data acquisition method via LA-ICP-MS, when compared to the Electron Microprobe, measured data from CRUZ et al. (2007), enable us to further discuss orbital and millennial scale changes since the resolution is improved and instrumental noise reduced. The ln(Sr/Ca) vs. ln(Mg/Ca) slope for the Bt2 stalagmite is 0,91388 ± 0,0013 (r^2 = 0,69) showcasing the expected trend if Prior Calcite Precipitation (PCP) is the major process dictating the abundances of Mg and Sr in the stalagmite (SINCLAIR, 2011).

The Sr/Ca and Mg/Ca values are positively correlated with $\delta^{18}O$ of Bt2 speleothem (r^2 =0.40) indicating a significant relationship between increased local rainfall with intensification of monsoon circulation as indicated by lower values of both trace element and stable oxygen ratios. We also observe a near perfect fit between Sr/Ca, Mg/Ca, $\delta^{18}O$ and insolation curves during the first two precession cycles of the last glacial period (Fig. 2). From ~65 ky BP to ~44 ky BP the Sr/Ca and Mg/Ca normalized data stay close to neutral values in the first's values in orbital scale and persistently negative in the case of latter ratios, both curves show a plateau-shaped curve. Unlike the isotopic curve, the trace element ratios are decoupled from the insolation curve, which shows a very good match with it until ~44 ky BP. The trace element and isotopic data have a strong correlation within themselves but a weaker one with the insolation curve from ~42k yrs onwards as the amplitude of insolation decreases with the lower eccentricity that characterizes the Marine Isotope Stage (MIS) 3 and 2. As the amplitude of the insolation decreases, the signal of millennial-scale events becomes a key feature of the speleothem trace element variability.

At the millennial timescales, some of the negative anomalies observed in the speleothem $\delta^{18}O$ are also identified in both Mg/Ca and Sr/Ca ratios of Bt2 speleothem, for instance in the HS10, HS6, HS4, HS3, HS2 and HS1 events and some Greenland Stadials events (GS-5.2, 10, 15.2, 16.1 and 25) (Fig. 2). The climatic responses in other events are not very clear like in the HS7a or even absent, as appears to be the case with the events HS5 and 5a (Fig. 2). In contrast, the relationship between trace elements and $\delta^{18}O$ during the Greenland Interstadial (GI) periods have a less consistent signal on the Bt2 multiproxy time series. An exception occurs during the GI-1 (Bølling-Allerød Event) when we observe one of the highest positive anomalies of trace element ratios on the entire Bt2 record. A couple of positive anomalies are present only on the $\delta^{18}O$ record (GI-4 to 5.2, 14, and 19.2 to 22), suggesting a difference in the amplitude of response between the source area of moisture ($\delta^{18}O$) and amount of rainfall (Mg/Ca and Sr/Ca).

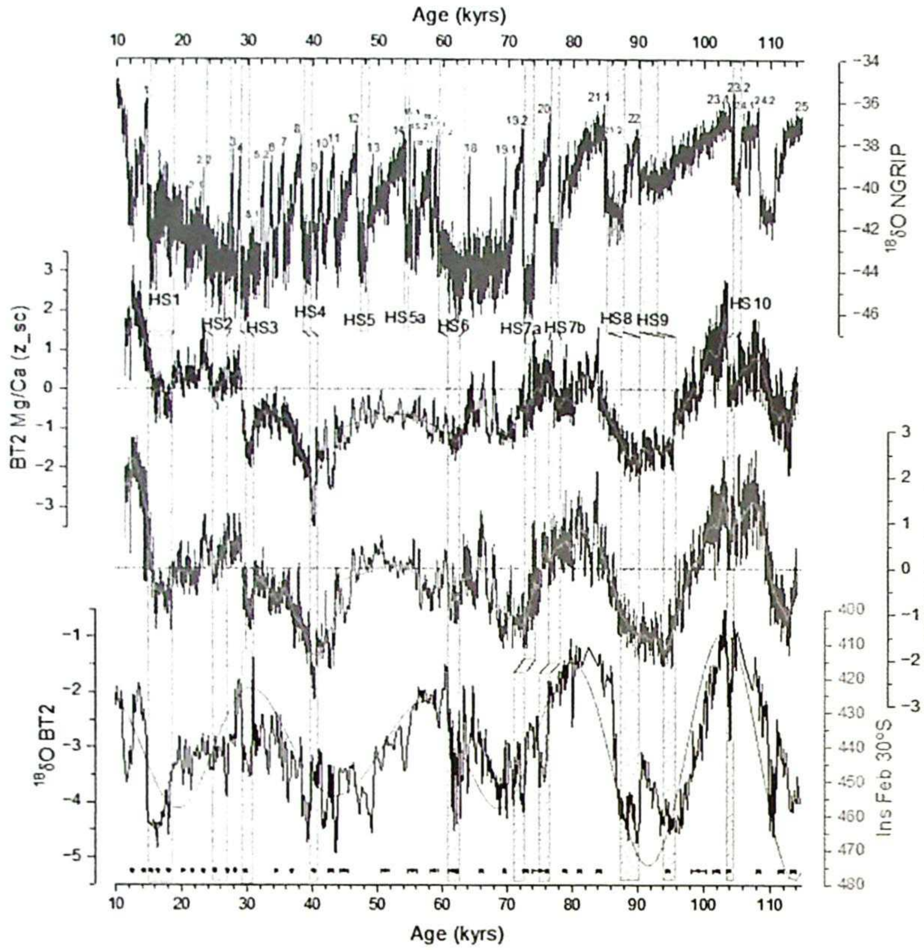

Figure 2: Bt2 stalagmite (Botuverá cave) δ18O (‰VPDB) (black), Sr/Ca (z-score) (red) and Mg/Ca (z-score) (blue) data covering the last 113.5 kyrs. δ18O NGRIP record (‰V-SMOW) from SEIERSTAD et al. (2014) (green). Dashed gray boxes indicate Henrich stadials events and red numbers on top of the NGRIP curve marks Greenland Interstadials periods. February Insolation for 30°S (W/m²) (orange) (BERGER and LOUTRE, 1991).

4. Discussion

Due to the complexity in interpreting δ18O variability because of the different moisture sources affecting southeastern Brazil, we are now presenting high-resolution trace elements data from a Botuverá cave speleothem, which allows us to compare the changes in SAMS intensity with moisture sources, providing a more robust paleoclimate reconstruction at distinct time scales. Because of the higher coherence between trace elements and δ18O data throughout the record, we are interpreting the lower (higher) Sr/Ca and Mg/Ca point towards more (less) rainfall recharge in the vadose zone of the karst due to less (more) intensification of Prior Calcite Precipitation (PCP) in caves over subtropical Brazil (KARMANN et al., 2007). A significant outcome of this comparison is the identified correlation between monsoon intensity variations and annual average precipitation (CRUZ et al., 2007; BERNAL et al., 2016), even if the region is influenced by a bimodal rainfall regime characterized by distinct rain source areas.

Between 114 and 65 ky BP, the δ18O, Sr/Ca and Mg/Ca show a good match with changes in summer insolation over two precession cycles. Periods of high summer insolation align with decreased values in oxygen isotope ratios and trace element ratios. In contrast, periods of low summer insolation correspond to increased values (Fig. 2). In this regard, the increase in local rainfall recharge on orbital timescales during periods of enhanced monsoon rainfall in the region coincides with phases of high austral summer phases as it was already discussed in previous works (CRUZ et al., 2007; BERNAL et al., 2016).

In comparison, the trace element curves from 65 to 10 ky BP do not seem to follow the variation in insolation so well. The Mg/Ca and Sr/Ca suggest that other climatic forces have a major influence on the changes in rainfall over subtropics. The Bt2 geochemical record consistently exhibits negative or neutral anomalies in trace element ratios. These anomalies were initially attributed to cooler water conditions in the North Atlantic, which enhanced moisture transport from the equatorial Atlantic Ocean to the Amazon Basin, thereby contributing to the intensification of the SAMS (CRUZ et al., 2007). These prevailing negative δ18O anomalies are also observed in other speleothem isotope records from subtropical Brazil like in Santana cave (CRUZ et al., 2006).

During most of Heinrich Stadials events, both negative isotopic and trace element incursions confirm the coupling between increased monsoon-amazon sourced moisture and higher rainfall amount in the region. The results indicate the common occurrence of wet events in South American subtropics marked by lower Mg/Ca and Sr/Ca values as a response to the SAMS intensification, as reported in the speleothem δ18O records from tropical eastern Brazil during cold stadials in the North Atlantic (STRIKIS et al., 2018). This is an important result because, even though the impact of the Heinrich events is already well known, there was still no confirmation of the increase in the average annual rainfall so far. In addition, these findings indicate that the isotopic signal of speleothems primarily reflects local rainfall dynamics rather than solely the upstream fractionation of moisture through the Degree of Rainout process along its trajectory from the Amazon (AMPUERO et al., 2020) or at its origin in the Atlantic Ocean (BAO et al., 2023).

Although warm Greenland Interstadials (GIs), also known as Dansgaard-Oeschger (DO) events, are distinctly visible in tropical speleothem records from the Intertropical Convergence Zone (ITCZ) region, the Peruvian Andes, and eastern Brazil, their expression is less pronounced in the trace element records of the Botuverá speleothem. However, some events, such as GI 14 and GI 22, are discernible in the $\delta^{18}O$ records (Fig. 2). An exception is the Bølling-Allerød event, which exhibits one of the most pronounced Sr/Ca and Mg/Ca anomalies between 15 and 12 kyr BP, indicating one of the driest periods recorded in the region during the last glacial period.

For the first time, we can describe a very consistent relationship between increased (decreased) monsoon rainfall during the last glacial period, as defined by lower (higher) values in trace element ratios, and cooler (warmer) sea surface temperatures (SST) in the subtropical South Atlantic. An interesting aspect of this comparison is that the speleothem-Sr/Ca and marine-SST data follow together the summer insolation phases according to the precession cycle between 116 and 65 ky BP. Furthermore, the relationship remains consistent even in the period in which the proxy data decouple from the insolation curve. Notably, the plateau observed in the Sr/Ca data from 65 to 45 kyr BP coincides with elevated SST values. Similarly, the trend of increase in trace elements follows the increase in SST observed from 40 ky BP to 25 ky BP and between 15 and 13 ky BP, during the Bølling–Allerød Interstadial event. On the other hand, the strong relationship between lower Sr/Ca values of Bt2 speleothem and cooler SSTs in subtropical data is also noteworthy during HS4, HS3, and HS1 events.

The comparison between the geochemical data of speleothems and ln(Ti/Ca) from the same cores used to discuss SST variations allows us to suggest two modes of long-term precipitation variability. The first is associated with a rainfall pattern that encompasses a large region from about 20°S in the central region of the SACZ (core M125-55-7; HOU et al., 2020) to 27°S, where the Botuverá cave is located. This pattern extends southward to the region of the La Plata Basin, from where most of the river sediments transported to the site at 25°S (GL-1090) were carried (MATHIAS et al., 2021). It likely reflects a rainfall variation in phase across the area covered by SACZ and ALLJ, which operated between 115 and approximately 55 ky BP in the region with a first-order control of insolation forcing on climate. This regional hydrological pattern is supported by the speleothem isotope record from Santana Cave, located at 24°S (CRUZ et al., 2006; 2007).

The other mode of variability identified was a precipitation dipole between the SACZ region and the area fed by the moisture path related to the ALLJ. This mode can be observed from 55 to 11 ky BP, observed between the ln(Ti/Ca) data of marine sedimentary cores located at 20°S and 25°S in the western margin of the Atlantic. This dipole-like pattern of opposing summertime rainfall anomalies is well known in Southern Brazil and the La Plata Basin on modern time scales and resembles the intraseasonal mode known as SACZ and Southeast South America (SESA) (DIAZ and ACEITUNO, 2003). We consider that the drought trend indicated in the BT2 speleothem data from 40 ky BP onwards represents both a retraction of SACZ rainfall northwards towards its modern axis and a decrease in rainfall associated with a weaker moisture transport by the ALLJ. This precipitation pattern makes perfect sense with the variations of SST observed in this period, which is characterized by cooling in the adjacent ocean in the SACZ region and warming further south, in the subtropical region of South America that correspond to the wet and dry areas of the South American Monsoon during this period, respectively.

5. Conclusion

Our new LA-ICP-MS trace element data from Botuverá Cave indicates that periods with enhanced (weakened) SAMS correspond to increased (decreased) local rainfall amount, signaled by lower (higher) $\delta^{18}O$, Sr/Ca and Mg/Ca values during the Last Glacial Period. On orbital time-scale, we have identified that insolation is the main climate forcing at the first half of Last Glacial Period from 115 to 65 kyrs, while climate conditions associated with AMOC seems do exert a more important control on the long-term change in SAMS rainfall between 65 to 15 kyrs. By comparing our speleothem isotope record and marine sediment core data from the subtropical South Atlantic, it is observed a clear relationship between increased local precipitation and cooler SST in the subtropical western South Atlantic throughout the Last Glacial Period, a result indicating that cloud cover can significantly influence sea surface temperature during the first high austral summer insolation phases. In that sense, the increased Zonal SST gradients due to weakened AMOC conditions towards MIS 3 and 2 can explain the warming SST trend at 25°S, but not the cooling one at the 20°S site after 55 ky BP, which highlights the importance of cloud cover in modulating SST variations over the South Atlantic.

On millennial-scale, we observed that the negative isotopic and trace element anomalies during most HSs are strong evidence of SAMS intensification and local rainfall increase over South Brazil during most of the cold North Atlantic events. However, the climate response to GIs or DOs events are barely observed in the Sr/Ca and Mg/Ca record, while some of them result in positive $\delta^{18}O$ anomalies at Botuverá. This suggests a weakening in the influence of North Atlantic warm millennial variations when we compare our subtropical South America record in relation to the consistent positive $\delta^{18}O$ speleothems record from lower latitudes during GIs. It is important to note that the Bolling-Allerod event is an exception, with one of the highest trace element values on our record, indicating an extremely dry period. For the HS1 in particular, we propose a precipitation dipole between sectors of the SACZ, because the dry phase centered around 16 ky BP for the northern sector interpreted by positive $\delta^{18}O$ anomalies is contemporaneous to a wet period on the southern sector responsible for negative $\delta^{18}O$, Sr/Ca and Mg/Ca anomalies.

References

AMPUERO, A., STRIKIS, N. M., APAESTEGUI, J., VUILLE, M., NOVELLO, V. F., ESPINOZA, J. C., ... & SIFEDDINE, A. (2020). The forest effects on the isotopic composition of rainfall in the northwestern Amazon Basin. Journal of Geophysical Research: Atmospheres, 125(4).

BAO, Y., LIU, Z., & HE, C. (2023a). Dipole response of millennial variability in tropical South American precipitation and δ 18 O p during the last deglaciation. Part I: Rainfall response. Journal of Climate, 36(14), 4691-4707.

BAO, Y., LIU, Z., & HE, C. (2023). Dipole response of millennial variability in tropical South American precipitation and δ 18 O p during the last deglaciation. Part II: δ 18 O p response. Journal of Climate, 36(14), 4709-4721.

BERGER, A., & LOUTRE, M. F. (1991). Insolation values for the climate of the last 10 million years. Quaternary science reviews, 10(4), 297-317.

BERNAL, J. P., CRUZ, F. W., STRIKIS, N. M., WANG, X., DEININGER, M., CATUNDA, M. C. A., ... & AULER, A. S. (2016). High-resolution Holocene South American monsoon history recorded by a speleothem from Botuverá Cave, Brazil. Earth and Planetary Science Letters, 450, 186-196.

CRUZ JR, F. W., BURNS, S. J., KARMANN, I., SHARP, W. D., VUILLE, M., CARDOSO, A. O., ... & VIANA JR, O. (2005). Insolation-driven changes in atmospheric circulation over the past 116,000 years in subtropical Brazil. Nature, 434(7029), 63-66.

CRUZ JR, F. W., BURNS, S. J., KARMANN, I., SHARP, W. D., & VUILLE, M. (2006). Reconstruction of regional atmospheric circulation features during the late Pleistocene in subtropical Brazil from oxygen isotope composition of speleothems. Earth and Planetary Science Letters, 248(1-2), 495-507.

CRUZ JR, F. W., BURNS, S. J., JERCINOVIC, M., KARMANN, I., SHARP, W. D., & VUILLE, M. (2007). Evidence of rainfall variations in Southern Brazil from trace element ratios (Mg/Ca and Sr/Ca) in a Late Pleistocene stalagmite. Geochimica et Cosmochimica Acta, 71(9), 2250-2263.

DÍAZ, A., & ACEITUNO, P. (2003). Atmospheric circulation anomalies during episodes of enhanced and reduced convective cloudiness over Uruguay. Journal of climate, 16(19), 3171-3185.

FOHLMEISTER, J. (2012). A statistical approach to construct composite climate records of dated archives. Quaternary Geochronology, 14, 48-56.

HOU, A., BAHR, A., SCHMIDT, S., STREBL, C., ALBUQUERQUE, A. L., CHIESSI, C. M., & FRIEDRICH, O. (2020). Forcing of western tropical South Atlantic sea surface temperature across three glacial-interglacial cycles. Global and Planetary Change, 188, 103150.

KANNER, L. C., BURNS, S. J., CHENG, H., EDWARDS, R. L., & VUILLE, M. (2013). High-resolution variability of the South American summer monsoon over the last seven millennia: insights from a speleothem record from the central Peruvian Andes. Quaternary Science Reviews, 75, 1-10.

KARMANN, I., CRUZ JR, F. W., VIANA JR, O., & BURNS, S. J. (2007). Climate influence on geochemistry parameters of waters from Santana–Pérolas cave system, Brazil. Chemical Geology, 244(1-2), 232-247.

MATHIAS, G. L., ROUD, S. C., CHIESSI, C. M., CAMPOS, M. D. C., DIAS, B. B., SANTOS, T. P., ... & MAHER, B. A. (2021). A multi-proxy approach to unravel late Pleistocene sediment flux and bottom water conditions in the western south Atlantic Ocean. Paleoceanography and Paleoclimatology, 36(4), e2020PA004058.

MILLO, C., STRIKIS, N. M., VONHOF, H. B., DEININGER, M., DA CRUZ JR, F. W., WANG, X., ... & EDWARDS, R. L. (2017). Last glacial and Holocene stable isotope record of fossil dripwater from subtropical Brazil based on analysis of fluid inclusions in stalagmites. Chemical Geology, 468, 84-96.

NOVELLO, V. F., CRUZ, F. W., VUILLE, M., STRIKIS, N. M., EDWARDS, R. L., CHENG, H., ... & SANTOS, R. V. (2017). A high-resolution history of the South American Monsoon from Last Glacial Maximum to the Holocene. Scientific reports, 7(1), 44267.

SANTOS, T. P., LESSA, D. O., VENANCIO, I. M., CHIESSI, C. M., MULITZA, S., KUHNERT, H., ... & ALBUQUERQUE, A. L. S. (2017). Prolonged warming of the Brazil Current precedes deglaciations. Earth and Planetary Science Letters, 463, 1-12.

SEIERSTAD, I. K., ABBOTT, P. M., BIGLER, M., BLUNIER, T., BOURNE, A. J., BROOK, E., ... & VINTHER, B. M. (2014). Consistently dated records from the Greenland GRIP, GISP2 and NGRIP ice cores for the past 104 ka reveal regional millennial-scale δ18O gradients with possible Heinrich event imprint. Quaternary Science Reviews, 106, 29-46.

SINCLAIR, D. J. (2011). Two mathematical models of Mg and Sr partitioning into solution during incongruent calcite dissolution: implications for dripwater and speleothem studies. Chemical Geology, 283(3-4), 119-133.

STRIKIS, N. M., CHIESSI, C. M., CRUZ, F. W., VUILLE, M., CHENG, H., DE SOUZA BARRETO, E. A., ... & SALES, H. D. R. (2015). Timing and structure of Mega-SACZ events during Heinrich Stadial 1. Geophysical Research Letters, 42(13), 5477-5484A.

STRIKIS, N. M., CRUZ, F. W., BARRETO, E. A., NAUGHTON, F., VUILLE, M., CHENG, H., ... & SALES, H. R. (2018). South American monsoon response to iceberg discharge in the North Atlantic. Proceedings of the National Academy of Sciences, 115(15), 3788-3793.

WANG, X., AULER, A. S., EDWARDS, R. L., CHENG, H., ITO, E., WANG, Y., ... & SOLHEID, M. (2007). Millennial-scale precipitation changes in southern Brazil over the past 90,000 years. Geophysical Research Letters, 34(23).

WANG, X., EDWARDS, R. L., AULER, A. S., CHENG, H., KONG, X., WANG, Y., ... & CHIANG, H. W. (2017). Hydroclimate changes across the Amazon lowlands over the past 45,000 years. Nature, 541(7636), 204-207.