We are grateful for the community comments on manuscript cp-2023-2. We addressed the community's comments below in italicized text.

CC1

Comments on "Spatiotemporal ITCZ dynamics during the last three millennia in Northeastern Brazil and related impacts in modern human history."

Authors: Giselle Utida, Francisco William Cruz, Mathias Vuille, Angela Ampuero, Valdir F. Novello, Jelena Maksic, Gilvan Sampaio, Hai Cheng, Haiwei Zhang, Fabio Ramos Dias de Andrade, and R. Lawrence Edwards

This is an interesting study that uses speleothem δ18O and δ13C records to characterize the nuanced behavior of the ITCZ/tropical rain belt and its impact on the regional hydroclimate (i.e., precipitation variability) of Nordeste and eastern Amazona during the late Holocene. The main objective of this study is to improve the interpretation of late Holocene ITCZ dynamics in the South American tropics, which may help to better our understanding of past SASM variability. Additionally, their interpretation of RN δ18O as a recorder of extreme dry events during the last 500 years has archeological and societal implications. This manuscript presents several thought-provoking and novel ideas pertaining to Atlantic and Pacific impacts on ITCZ-related precipitation during the late Holocene, which have the potential to reconcile paleoclimate records from Nordeste and Amazonia. Overall, this study also has the potential to be an excellent contribution to the field of South American paleoclimatology. However, I find that the manuscript (in its present state) has several major issues, which require further consideration, detail, and development before it should be accepted for publication. As such, I would recommend major revisions of the manuscript before final acceptance.

Major issues:

1. I am concerned that the AMV reconstruction presented in figure 5 (also referenced in the main text) is misleading. Specifically:

Figure 5 (and lines 451–454): It is true that the presented AMV time series and the RN composite δ18O time series look similar, but it is unclear what the authors are plotting. The green time series in figure 5 (shown below, top figure) does not look like the AMV reconstruction from Lapointe et al. (2020) (shown below, bottom figure)—raw data from https://www.ncei.noaa.gov/access/paleo-search/study/31353. The full range of values from the Lapointe dataset is 21.7–22.7, while the reconstruction shown in figure 5 only appears to be from 21.95 to 22.40.

Perhaps the authors plotted a different reconstruction of the AMV and used the wrong citation? Or perhaps it is the reconstruction from Lapointe et al. (2020) but downsampled (if so, the authors need to make this clear in the methods or supplementary information)?

Thank you for your comment and question. We addressed this point in the response to reviewer`s comments (RC1, comment 19). We incidentally plotted the AMV curve (Lapointe et al., 2020) backwards in the original manuscript. We have corrected the figure and the discussion based on the AMV. We invite you to read our response to the reviewers as it should help clarify your question.

2. The authors do not sufficiently explain the mechanisms driving the anti-phased behavior observed between the RN composite and Paraíso Cave δ18O records. Specifically:

Lines 436–440: It is unclear what is meant by "a zonal behavior of precipitation shifts in the ITCZ domain." Are the authors proposing that RN and Paraíso are in-phase from 250–1100 CE, anti-phased at ~1100 CE, back in-phase from 1100–1500 CE, and then anti-phased again from 1500–1750 CE? The authors should provide more explanation for this behavior.

Additionally, the authors state that "even though the Paraíso and Cariaco sites are located in different hemispheres, the observed in-phase climate relationship during the LIA suggests that their isotopic signatures were both sensitive to the same rainfall changes over northern South America." The Cariaco record is not an isotope-based record. Rather, it is a bulk titanium % record. The wording of this sentence should be changed accordingly.

The Paraíso record cannot be interpreted in the same way as the RN record that predominantly receives rainfall originating from the ITCZ, while the Paraíso Cave is located at the margin of two different systems, the ITCZ and the South American Summer Monsoon (SASM), as described in our Climatology section (Figure 2). The location of Paraiso at the very edge of the SASM region likely explains why during certain intervals it varies in-phase and during others out of phase with the RN record. As shown by Orrison et al. (2022) during the last millennia the Paraiso record tends to be out of phase with the core monsoon region as a result of Bolivian-High-Nordeste Low intensification. However, a slight zonal shift of this leading mode of monsoon variability would change this relationship, as the Paraiso record would become part of the monsoon system, leaving it antiphased with the subsidence region over NE Brazil, where the RN record is located. Hence, the location of Paraiso at the node of this dipole, renders its response very sensitive to slight changes in the monsoon core. Furthermore, the zonal precipitation gradient between northeastern Brazil and the eastern-central Amazon is highly sensitive to changes in Pacific and Atlantic SST on multidecadal timescales. As shown by He et al. (2021), during the monsoon season (DJF), the zonal precipitation gradient response to Pacific SST variability completely reverses in this region, depending on the state of the Atlantic (see Figure 7 in He et al., 2021) and this change is transmitted via a perturbed Walker circulation (see their Figure 9). We now reference this mechanism in the revised paper, but discussing in great depth the joint interactions between Pacific and Atlantic and how they perturb Hadley and Walker circulation, respectively, is beyond the scope of this paper. We refer the interested reader to He et al. (2021) instead.

We have also revised the text in order to clarify that Cariaco is not an isotopic record.

We have rewritten this paragraph to adjust the discussion about the RN Composite the Paraíso and Cariaco records, respectively, according to suggestions we received from RC1 and 2. Please see our revised version below.

"When comparing N-NEB and eastern Amazon conditions, it is evident that the RN Composite shares some similarities with the Paraiso stalagmite record (Wang et al., 2017), due to the contribution of ITCZ precipitation in both places. But there are also important differences (Fig. 4). The RN Composite shows lower $\delta^{18}O$ values between 500 and 1000 CE, compared to the earlier period, while Paraiso shows decreasing values around the same period, suggesting a slight increase in precipitation in both areas. From 1160 to 1500 CE, abrupt increases in $\delta^{18}O$ values are seen in both records, which indicates abrupt and prolonged drought conditions due to a northward ITCZ migration. However, around 1100 CE, and the period from 1500 to 1750 CE, Paraiso is antiphased with the RN Composite and in phase with the Cariaco Basin (Haug et al., 2001), which is inconsistent with the notion of an ITCZ-induced regional precipitation change.

Instead, a zonally-oriented precipitation change within the ITCZ domain over Brazil is required to explain the anti-phased behavior between precipitation in N-NEB and the eastern Amazon, and similarities between Cariaco and the eastern Amazon."

Lines 446–451: Here, the authors discuss the AMV and ITCZ displacement during a warm AMV. However, the authors have not defined what a warm AMV is, albeit the reader could find out in the cited studies. I recommend the authors specifically define the AMV in detail, and make clear what is meant by a warm vs cold AMV.

We will clarify in the revised manuscript how warm and cold AMV are defined.

Lines 461–463: The authors state, "Our analysis corroborates with this and points to increasing precipitation over N-NEB and decreasing precipitation over eastern Amazon, between 1500–1750 CE, when both AMV and PDV are in cold phase (Fig 4)." There is no reference to the PDV in figure 4, nor has the PDV been described/defined yet at this point in the text. No PDV reconstructions are provided in any of the figures, and the provided AMV reconstruction is in figure 5, not figure 4. Last millennium SST gradients from Steinman et al. (2022) are provided in figure 5, but they are not PDV or AMV reconstructions. I recommend either including a PDV reconstruction in one of the figures, or to remove this text from the manuscript.

Lines 463–465: The authors state, "This sign reversal is assigned to perturbations of the regional Walker cell's produced by teleconnection between the Atlantic and Pacific (Kayano et al., 2022, He et al., 2021)." I find this explanation to be vague, and recommend that the authors provide a clearer and more detailed explanation for the sign reversal. What does "perturbations of the regional Walker cell's" mean exactly? What teleconnections are the authors referring to, and what are the mechanisms driving the aforementioned perturbations?

The Figure presents only the AMV. The discussion about the relationship between AMV and PDV was only based on an observed precipitation analysis. We made some adjustments in the paragraph to clarify the aspects mentioned in the last two comments. Please see the revised text below.

"According to Kayano et al. (2020, 2022), during the last century, dry conditions over N-NEB and the eastern Amazon are present when AMV and Pacific Decadal Variability (PDV) are in both in their warm phase, or when the AMV is in a cold phase and the PDV in its warm phase. On the other hand, when AMV and PDV are both in their cold phase, precipitation over the Amazon is anti-phased with NEB, resulting in decreased precipitation over the Amazon and increased precipitation over NEB. This zonally aligned precipitation signal over eastern tropical S. America is the result of joint perturbations of both the regional Walker and Hadley Cell's, produced by teleconnection between the Atlantic and Pacific (Kayano et al., 2022, He et al., 2021). These conditions can explain in part our results, however during the decoupling of our record with AMV (between 1500 and 1750 CE), increasing precipitation over N-NEB and decreasing precipitation over the eastern Amazon can be better explained by the positive gradients both in Atlantic and Pacific Oceans forcing a south ITCZ migration (Fig. 4)."

3. The conclusion and abstract both discuss ITCZ dynamics forced by the AMV and PDV, including position, intensity, and width. However, in the main text, the authors do not sufficiently explain which dynamical aspect of the ITCZ responds to different AMV/PDV phases, nor do they explain any mechanism(s) behind the AMV/PDV forcing. Specifically:

Lines 570–577: In this paragraph, the authors suggest that during the last millennia, ITCZ dynamics cannot be explained solely by north-south ITCZ migrations or one single forcing mechanism. They propose a zonally non-uniform behavior of the ITCZ during times when the RN 4 record is anti-phased with the Paraíso cave record—forced by the interactions between the AMV and PDV modes that changed the regional Walker cell position and ITCZ intensity/width.

However, the authors never really attributed the anti-phased behavior between N-NEB and eastern Amazonia to the differential AMV/PDV phases. They discussed observed precipitation anomalies during overlapping periods of AMV and PDV phases in the modern, and suggested that it could be responsible for the observed anti-phased behavior. However, they never directly compared the speleothem time series with AMV and PDV reconstructions. Nor did the authors propose a detailed mechanism for how different AMV/PDV phases impact ITCZ width/intensity, despite changes in ITCZ width/intensity also being mentioned in the abstract (lines 46–50). In addition, the authors did not really describe when the ITCZ may have expanded/contracted or became weaker/stronger (aside from stating that this may have happened when the RN composite record and Paraíso are anti-phased). Ultimately, they never describe mechanism(s) for 1) how different AMV/PDV phases impact ITCZ dynamics, 2) how changes in ITCZ width/intensity may cause the observed anti-phased behavior, and 3) how the regional Walker cell position is forced by different AMV/PDV phases. I recommend that the authors provide more detail to this part of the Conclusions and Discussion sections overall, and propose/explain specific mechanisms that can reconcile the observed hydroclimate variability in N-NEB and eastern Amazonia.

We have responded to this comment above.

Additional note: The authors should be extremely clear when generally discussing ITCZ width/intensity. What exactly do the authors mean by ITCZ width? Is it the width of the actual band of deep convection? Width of the seasonal range of the ITCZ? These terms should be explicitly defined early in the manuscript. Some papers that may be useful to reference include Donohoe et al. (2013), Atwood et al. (2020), Byrne and Schneider (2016), and Roberts et al. (2017).

The ITCZ definition adopted is the one referring to it as the modern tropical rain belt of maximum precipitation and the ITCZ position is defined according to Schneider et al. (2014). The position is mentioned in line 160 of the manuscript, when we define the locality of our study site and its relationship with the ITCZ. We will add to this definition by including the ITCZ position during the boreal winter over the Atlantic (2° N). We will change the term "ITCZ width" by "ITCZ length". We were referring to the duration of the ITCZ over N-NEB, from March to May, during its southernmost extent, but we did not intend to imply a specific ITCZ dimension. We will rephrase how we refer to the ITCZ's southernmost expansion in MAM to avoid confusion.

Additional comments and concerns:

Lines 89–92: The authors cite Lechleitner et al. (2019), but I believe the correct citation is Lechleitner et al. (2017). Additionally, another relevant citation that may be relevant and could be included here is Asmerom et al. (2020) published in Science.

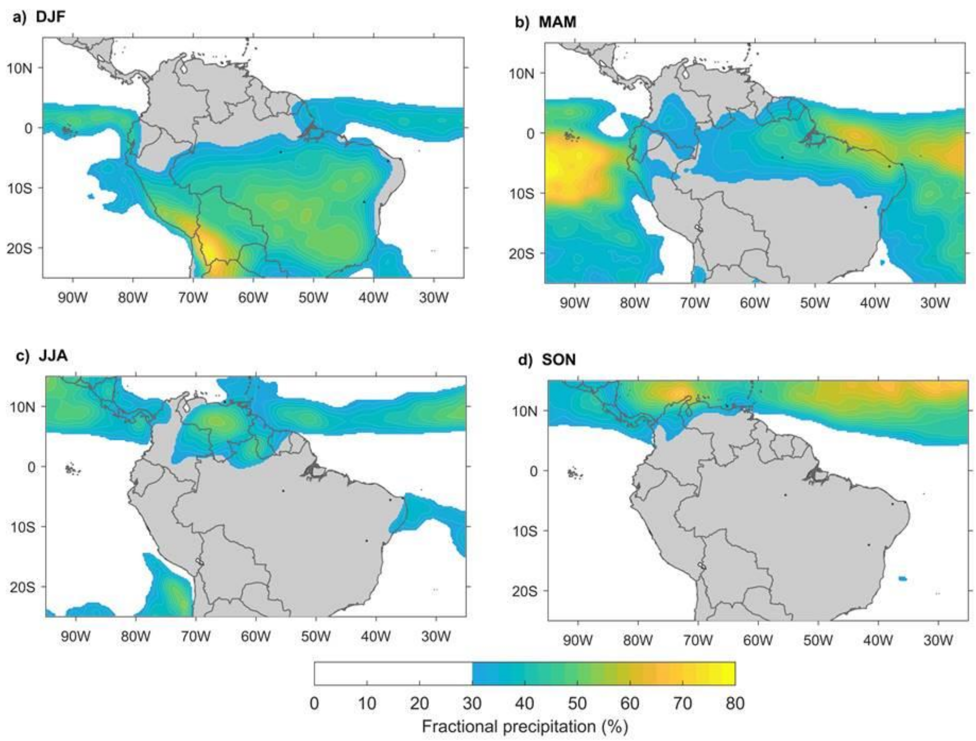
The citation will be corrected in the text. We will consider including other references as appropriate in the manuscript.

Lines 95–102: The authors call out the SASM and the ITCZ here as focus points of recent studies on tropical South American precipitation, but have not mentioned the South Atlantic Convergence Zone (SACZ). While not explicitly relevant to their findings, the SACZ should at least be mentioned here because of its important relationship with the SASM and ITCZ, and because it has been the topic of several recent paleoclimate and modern precipitation studies (Novello et al., 2018; Nielsen et al., 2019; Zilli et al., 2019; Wong et al., 2021).

We will include a brief discussion of the SACZ in the Introduction section, although the SACZ is not directly responsible for the precipitation observed at our study sites.

Figure 1: It may help the reader to include annotations in the figure, including labeling the core SASM domain, ITCZ location, SACZ, etc. Additionally, while I understand the choice to include austral autumn precipitation climatology (when N-NEB receives most of its precipitation), it may be worthwhile to include panels with precipitation climatology for the austral winter and spring (either added to figure 1 or included in the supplement). This would allow for the reader to visually assess the spatiotemporal dynamics of the ITCZ, SASM, and SACZ, and how precipitation varies at sites 1–4 during the different seasons. 5

We will consider including the annotations of ITCZ, SASM and SACZ in Figure 1. However, including fractional precipitation panels for JJA and SON does not add much relevant information for our region as precipitation at this time of year is low (see panels below). We therefore prefer to focus on the key rainy seasons DJF and MAM.



Lines 165–174: Figure S1 receives a lot of attention in this paragraph, and should probably be included as a main text figure. Alternatively, it could be incorporated into an existing main figure.

We will change this section and include the text related to the climatology of the region and Figure 2 in the results section instead, following to RC2’s suggestion. Certainly, Figure S1 can be included in the main text.

Figure 2: Readers who are green-red colorblind will not be able to see the small green dots (that denote the location of the GNIP stations) in any of the panels. I recommend changing the color to black and potentially increasing the size of the dots.

The journal editorial team already mentioned that we had to adapt the figure for color blind readers during the revision stage. All figures in the manuscript are now adapted accordingly.

Lines 362–363: It gets confusing when the authors use both before present (BP) dates and before common era/common era (BCE/CE) dates. Additionally, ky has not been defined before this point, so the authors should spell it out before using the abbreviation.

The nomenclature of the time periods will be standardized.

Figure 3: Same red–green issue as mentioned in Figure 2.

The journal editorial team already mentioned that we had to adapt the figure for color blind readers during the revision stage. All figures in the manuscript are now adapted accordingly.

Figure 4: It would be extremely helpful for the authors to include vertical bars when referencing specific time periods in the text. Such periods include the LIA, MCA, Bond 2 event, etc. Additionally, the authors reference trends resulting from insolation forcing in the paragraph starting at line 417.

The authors should consider including a time series of solar insolation.

We have included the insolation curve and also vertical bars in Figure 3 and 4 of the manuscript. This Figure in question already contains a lot of information and adding even more would make it difficult to read. We will instead add the insolation curve to the Figure S5 in the Supplement as shown below.

Also, the δD record from Boqueirão Lake is relative to VSMOW, not VPDB (Utida et al., 2019). This appears to be a typo and should be changed accordingly.

We have corrected this typo. Thank you for drawing attention to it.

Lines 389–392: The authors state that from 1060 to 480 BCE, there was increased precipitation in N-NEB as suggested by negative δ18O anomalies. But it is unclear what the authors mean by 'increased precipitation'. During this time, there is multidecadal variability in the RN composite δ18O record, but no clear/obvious trend between 1060 and 480 BCE. Perhaps the authors meant that there was increased precipitation *relative* to another part of the record. I would recommend clearing this up.

We have rewritten this paragraph to clarify our statement. Please see below.

"The oldest period covered by the RN Composite, from 1200 to 500 BCE, is characterized by successive dry and wet multidecadal periods, with increased precipitation in N-NEB from 1060 to 750 BCE and from 460 to 290 BCE, as suggested by the negative departures seen in the $\delta^{18}O$ values. During this last period, there is also a tendency from lower to higher $\delta^{13}C$ values, suggesting progressive surface soil erosion

related to rainfall variability (Fig. 4), as interpreted by Utida et al. (2020). This period ends in a stable interval, lasting from 300 BCE to 0 CE, with $\delta^{13}C$ values close to the bedrock signature at about -1‰ to +1‰, indicating a lack of soil above the cave. After an abrupt reduction of $\delta^{13}C$, the values decrease to approximately -2‰ between 200 CE and 1500 CE. From 1500 CE to the present, negative values of $\delta^{13}C$ represent wet climatic conditions as indicated by lower $\delta^{18}O$ values. The more negative $\delta^{13}C$ during this period can be related to denser vegetation that favored both soil production and stability above the cave."

Lines 408–409: The authors reference the δD record from Boqueirão Lake, and the same record is shown in figure 4. However, the authors describe the record as a "δD lipids" record. Lipids are a broad group of molecules which include waxes, glycerides, terpenoids, tetrapyrrole pigments, etc. The authors should be more specific, and should reference the record as a leaf wax δD record of *n*-C28 alkanoic acids from Boqueirão Lake sediments (hereinafter referred to as δD lipids).

We will include the description "n-C28 alkanoic acid obtained in leaf waxes" when first discussing the δD record from Boqueirão Lake (Utida et al., 2019).

Lines 495–497: The authors focus their discussion of extreme dry events recorded in the TRA5 δ18O record between 1500 and 1850 CE. However, it is unclear why the authors do not discuss dry events/distinct δ18O peaks after 1850 CE, despite their record extending into the 21st century. Is it because the TRA5 speleothem chronology is not as precise during this time?

The TRA5 chronology during the last 150 years is indeed not precise enough to discuss historical events. Since we will improve our discussion of age models, according to RC's2 suggestion, the TRA5 chronology will also be better explained and we will clarify this question in the updated version of the manuscript.

Lines 518–523 and Figure 6: The authors reference several historical droughts that had severe societal/socioeconomic consequences. It may be helpful to annotate figure 6 to highlight the most severe droughts referenced in the text. The number/letter labeling in figure 6 makes it hard to discern the severity of the droughts by looking at the figure alone. 6

According to the historical records, the most significant drought events registered in our stalagmite are related to points 4, 6 and 7. They will be highlighted in Figure 6 and mentioned in the caption.

Lines 533: The authors should provide more detail here. Which Governor are the authors referring to? Governor of what/where?

The Governor mentioned here is the Brazilian Governor. In that period, Brazil was a colony of Portugal and there was a local government. We will specify this in the text as "Brazilian Governor".

Figure 6: Why focus on just TRA5? TRA7 and FN1 appear to cover the same period as TRA5. Is TRA5 the only speleothem that records the extreme drought events? Do TRA7 or FN1 record any of the same drought events? If they do not, why would only one speleothem record these drought events and not the others?

Thank you for your comments and question. We addressed this point in the reviewer's comments. We invite you to please read our response in those files and hope they will help clarify your question.

It may be helpful to include the age uncertainty in the right panel of the figure under the heading "TRA5". For example, 1546 ± XX. Especially because this figure focuses on only the last 500 years, it would allow the reader to critically compare the speleothem dates to the historical drought dates listed in the column labeled "Historical."

Thank you for your comments and question. We addressed this point in detail in the RC2's comments considering the U/Th ages and age model. We invite you to please read our response in those files and hope they will help clarify your question.

Additionally, I am curious if there is an available archeological record(s) or something similar that could be plotted with the TRA5 δ18O record. Especially since the authors discuss the societal implications of the extreme droughts in relation to human population and welfare, it would be useful for the reader to visualize the impact through comparison with the speleothem record.

The Brazilian archeological records were discussed and compared with stalagmite data during the Holocene by Utida et al. (2020). However, these data basically describe the total population size during random intervals (https://memoria.ibge.gov.br/historia-do-ibge/historico-dos-censos/dados-historicos-dos-censos-demograficos.html) and they are not helpful to discuss episodic extreme events. Furthermore, considering the lack of demographic data in Brazil, from 1500 to 1870 CE, such a comparison with the stalagmite record, unfortunately, is not feasible.

Line 565–567: The authors state, "The N-NEB record presents a trend toward drier conditions as is also being observed in the Diva de Maura Cave in S-NEB, interpreted as an ITCZ withdrawal and SASM weakening, respectively." It is unclear what the authors mean by "ITCZ withdrawal," especially since the authors highlighted the dynamical behavior of the ITCZ earlier in the paper. Is it a withdrawal via mean ITCZ displacement? Contraction or weakening of the ITCZ? More detail here would be helpful for the reader.

'Withdrawal' of the ITCZ was meant to indicate that it's mean position moved northward. We will clarify this in the revised version of the manuscript.

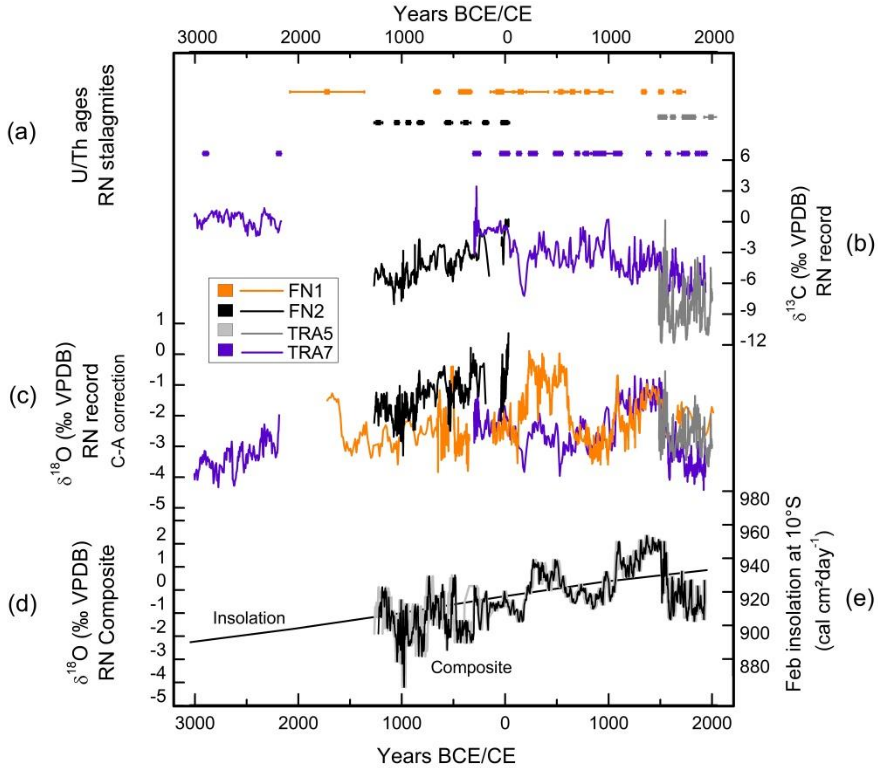


Figure S5 – Rio Grande do Norte stalagmite isotope record. (a) U/Th ages for RN stalagmites. (b) Raw data of $\delta^{13}C$. (c) Oxygen isotope results corrected for calcite-aragonite fractionation ($\delta^{18}O_{C\text{-}A}$), according to weight proportion of mineralogical results. (d) $\delta^{18}O$ RN Composite constructed using stalagmite records from NEB (black line). Grey lines denote the age model confidence interval of 99%. (e) February insolation curve at 10°S.

References:

Asmerom, Y., Baldini, J. U. L., Prufer, K. M., Polyak, V. J., Ridley, H. E., Aquino, V. V., Baldini, L. M., Breitenbach, S. F. M., Macpherson, C. G., and Kennett, D. J.: Intertropical convergence zone variability in the Neotropics during the Common Era, Sci. Adv., 6, eaax3644, https://doi.org/10.1126/sciadv.aax3644, 2020.

Atwood, A. R., Donohoe, A., Battisti, D. S., Liu, X., and Pausata, F. S. R.: Robust Longitudinally Variable Responses of the ITCZ to a Myriad of Climate Forcings, Geophysical Research Letters, 47, https://doi.org/10.1029/2020GL088833, 2020.

Byrne, M. P. and Schneider, T.: Energetic Constraints on the Width of the Intertropical Convergence Zone, Journal of Climate, 29, 4709–4721, https://doi.org/10.1175/JCLI-D-15-0767.1, 2016.

Donohoe, A., Marshall, J., Ferreira, D., and Mcgee, D.: The Relationship between ITCZ Location and Cross-Equatorial Atmospheric Heat Transport: From the Seasonal Cycle to the Last Glacial Maximum, Journal of Climate, 26, 3597–3618, https://doi.org/10.1175/JCLI-D-12-00467.1, 2013.

He, Z., Dai, A., and Vuille, M.: The joint impacts of Atlantic and Pacific multidecadal variability on South American precipitation and temperature, Journal of Climate, 1–55, https://doi.org/10.1175/JCLI-D-21-0081.1, 2021.

Kayano, M. T., Cerón, W. L., Andreoli, R. V., Souza, R. A. F., Avila-Diaz, A., Zuluaga, C. F., and Carvalho, L. M. V.: Does the El Niño-Southern Oscillation Affect the Combined Impact of the Atlantic Multidecadal Oscillation and Pacific Decadal Oscillation on the Precipitation and Surface Air Temperature Variability over South America?, Atmosphere, 13, 231, https://doi.org/10.3390/atmos13020231, 2022.

Lapointe, F., Bradley, R. S., Francus, P., Balascio, N. L., Abbott, M. B., Stoner, J. S., St-Onge, G., De Coninck, A., and Labarre, T.: Annually resolved Atlantic sea surface temperature variability over the past 2,900 y, Proc. Natl. Acad. Sci. U.S.A., 117, 27171–27178, https://doi.org/10.1073/pnas.2014166117, 2020.

Lechleitner, F. A., Breitenbach, S. F. M., Rehfeld, K., Ridley, H. E., Asmerom, Y., Prufer, K. M., Marwan, N., Goswami, B., Kennett, D. J., Aquino, V. V., Polyak, V., Haug, G. H., Eglinton, T. I., and Baldini, J. U. L.: Tropical rainfall over the last two millennia: evidence for a low-latitude hydrologic seesaw, Sci Rep, 7, 45809, https://doi.org/10.1038/srep45809, 2017.

Nielsen, D. M., Belém, A. L., Marton, E., and Cataldi, M.: Dynamics-based regression models for the South Atlantic Convergence Zone, Clim Dyn, 52, 5527–5553, https://doi.org/10.1007/s00382-018-4460-4, 2019.

Novello, V. F., Cruz, F. W., Moquet, J. S., Vuille, M., De Paula, M. S., Nunes, D., Edwards, R. L., Cheng, H., Karmann, I., Utida, G., Stríkis, N. M., and Campos, J. L. P. S.: Two Millennia of South Atlantic Convergence Zone Variability Reconstructed From Isotopic Proxies, Geophys. Res. Lett., 45, 5045–5051, https://doi.org/10.1029/2017GL076838, 2018.

Roberts, W. H. G., Valdes, P. J., and Singarayer, J. S.: Can energy fluxes be used to interpret glacial/interglacial precipitation changes in the tropics?, Geophys. Res. Lett., 44, 6373–6382, https://doi.org/10.1002/2017GL073103, 2017.

Steinman, B. A., Stansell, N. D., Mann, M. E., Cooke, C. A., Abbott, M. B., Vuille, M., Bird, B. W., Lachniet, M. S., and Fernandez, A.: Interhemispheric antiphasing of neotropical precipitation during the past millennium, Proceedings of the National Academy of Sciences, 119, e2120015119, 2022. 8

Utida, G., Cruz, F. W., Etourneau, J., Bouloubassi, I., Schefuß, E., Vuille, M., Novello, V. F., Prado, L. F., Sifeddine, A., Klein, V., Zular, A., Viana, J. C. C., and Turcq, B.: Tropical South Atlantic influence on Northeastern Brazil precipitation and ITCZ displacement during the past 2300 years, Sci Rep, 9, 1698, https://doi.org/10.1038/s41598-018-38003-6, 2019.

Wong, M. L., Wang, X., Latrubesse, E. M., He, S., and Bayer, M.: Variations in the South Atlantic Convergence Zone over the mid-to-late Holocene inferred from speleothem δ18O in central Brazil, Quaternary Science Reviews, 270, 107178, https://doi.org/10.1016/j.quascirev.2021.107178, 2021.

Zilli, M. T., Carvalho, L. M. V., and Lintner, B. R.: The poleward shift of South Atlantic Convergence Zone in recent decades, Clim Dyn, 52, 2545–2563, https://doi.org/10.1007/s00382-018-4277-1, 2019.

References

Atwood, A. R., Donohoe, A., Battisti, D.S., Liu, X., & Pausata, F. S. R.: Robust longitudinally variable responses of the ITCZ to a myriad of climate forcings. Geophys. Res. Lett., 47, e2020GL088833. https://doi.org/10.1029/2020GL088833R, 2020.

Cruz, F.W., Vuille, M., Burns, S.J., Wang. X., Cheng, H., Werner, M., Edwards, R.L., Karman, I., Auler, A.S., Nguyen, H.: Orbitally driven east-west antiphasing of South American precipitation, Nat. Geosci., 2, 210-214, https://doi.org/10.1038/ngeo444, 2009.

He, Z., Dai, A., Vuille, M.: The joint impacts of Atlantic and Pacific multidecadal variability on South American precipitation and temperature. J. Climate, 34(19), 7959-7981. https://doi.org/10.1175/JCLI-D-21-0081.1, 2021.

Kayano, M.T., Andreoli, R.V., de Souza, R.A.: Pacific and Atlantic multidecadal variability relations to the El Niño events and their effects on the South American rainfall, Int. J. Climatol., 40(4), 2183-2200, https://doi.org/10.1002/joc.6326, 2020.

Kayano, M.T., Cerón, W.L., Andreoli, R.V., Souza, R.A.F., Avila-Diaz, A., Zuluaga, C.F., Carvalho, L.M.V.: Does the El Niño-Southern Oscillation Affect the Combined Impact of the Atlantic Multidecadal Oscillation and Pacific Decadal Oscillation on the Precipitation and Surface Air Temperature Variability over South America?, Atmos., 13, 231, https://doi.org/10.3390/atmos13020231, 2022.

Lapointe, F., Bradley, R.S., Francus, P., Balascio, N.L., Abbott, M.B., Stoner, J.S., St-Onge, G., De Coninck, A., Labarre, T.: Annually resolved Atlantic Sea surface temperature variability over the past 2,900 y, Proc. Natl. Acad. Sci., 117, 44, 27171–27178, https://doi.org/10.1073/pnas.2014166117, 2020.

Orrison, R., Vuille, M., Smerdon, J. E., Apaéstegui, J., Azevedo, V., Campos, J. L. P. S., Cruz, F. W., Della Libera, M. E., and Stríkis, N. M.: South American Summer Monsoon variability over the last millennium in paleoclimate records and isotope-enabled climate models, Clim. Past, 18, 2045–2062, https://doi.org/10.5194/cp-18-2045-2022, 2022.

Schneider, T., Bischoff, T., Haug, G.H.: Migrations and dynamics of the intertropical convergence zone, Nature, 513, 7516, 45-53, https://doi.org/10.1038/nature13636, 2014.

Utida, G., Cruz, F.W., Etourneau, J., Bouloubassi, I., Schefuß, E., Vuille, M., Novello, V., Prado, L.F., Sifeddine, A., Klein, V., Zular, A., Viana, J.C.C., Turcq, B.: Tropical South Atlantic influence on Northeastern Brazil precipitation and ITCZ displacement during the past 2300 years, Sci. Rep., 9, 1698, https://doi.org/10.1038/s41598-018-38003-6, 2019.

Utida, G., Cruz, F.W., Santos., R.V., Sawakuchi, A.O., Wang, H., Pessenda, L.C.R., Novello, V.F., Vuille, M., Strauss, A.M., Borella, A.C., Stríkis, N.M., Guedes, C.C.F., De Andrade, F.D., Zhang., H., Cheng, H., Edwards, R.L.: Climate changes in Northeastern Brazil from deglacial to Meghalayan periods and related environmental impacts, Quat. Sci. Rev., 250, 106655, https://doi.org/10.1016/j.quascirev.2020.106655, 2020.

Wang, J., Yang, B., Ljungqvist, F.C., Luterbacher, J., Osborn, T.J., Briffa, K.R., Zorita, E.: Internal and external forcing of multidecadal Atlantic climate variability over the past 1,200 years, Nat. Geosci. 10, 512–517, https://doi.org/10.1038/ngeo2962, 2017.