Comment on egusphere-2022-785
Anonymous Referee #1

Review of "Multidecadal variability of the ITCZ from the Last Millennium Extreme Precipitation Changes in Northeastern Brazil" by Isela L. Vásquez P et al.

Referee Commentary
I would appreciate it if the authors would carefully revise the text again. On the one hand, there are still some incomplete sentences. On the other hand, the English is still inadequate, which sometimes leads to the fact that I cannot grasp the message of the sentences. Therefore, the manuscript should be revised linguistically, as sentences are not understandable.
Response:
Thank you for your comments. We apologize for any difficulties and confusion it may have caused. We appreciate your suggestions. The manuscript has been revised, paying special attention to the clarity of the structure, the main objective of the paper, and the description of the methods. We will also ensure that the English language is reviewed and corrected. Thank you again for your valuable input.

Referee Commentary
Please also check the content of the manuscript. Regardless of the linguistic difficulties, it seems to me that some statements are also implausible - perhaps simply due to inattentiveness during the writing process. For example: 'When comparing the trends in the δDwax data with the LFC2 of precipitation during the MCA, it is observed that for the ensemble model, negative trends predominate over the period, different from the ensemble model where positive trends predominate.'
Response:
It was corrected in the new version of the pre-print. This is part of the new manuscript:
Figure 4a shows the records from the Cariaco Basin, where a higher concentration of titanium (Ti) is observed during the MCA. This indicates that the ITCZ is located further north, providing humid conditions. In contrast, during the LIA, the Ti concentration in the Cariaco Basin decreases, indicating dry conditions (Haug et al., 2003). This condition is related to the southward migration of the ITCZ (Haug et al., 2001; Bird et al., 2011; Vuille et al., 2012; Novello et al., 2012). Therefore, the Ti concentrations in the Cariaco Basin are related to the meridional displacement of the ITCZ. When comparing the trends, we observe that the LFC components (2 and 4) overestimate precipitation during the LIA. While in Figure 4b, the trends of the Boqueirão Lake data (δD) and the LFC precipitation components (1 and 3) are shown, which are related to the southward displacement of the ITCZ. During the MCA, positive values of δD are observed, indicating dry periods in the NEB region associated with the southward movement of the ITCZ (Novello et al., 2012). However, the LFC components (1 and 3) overestimate the dry periods, showing both positive and negative trends. During the LIA, the LFC components (1 and 3) show positive trends for most of the period (1150 – 1749) and negative trends towards the end (1749 – 1849), along with negative values of δD. This indicates wetter periods in the northern region of NEB, as evidenced by the rise in the

water level of the Boqueirão Lake (Viana et al., 2014), which is associated with the southward position of the ITCZ. This southward position is also evident from the occurrence of droughts in the Cariaco Basin (Haug et al., 2003). In general, the LFC components indicate a tendency to underestimate dry conditions. These results were obtained through the analysis of the probability distribution of the ITCZ location. It is concluded that the CMIP6 models, although showing improvement in estimating the position of the ITCZ compared to CMIP5, still overestimate the variability and position of the ITCZ. However, these models are capable of reproducing large-scale changes in the position of the ITCZ in the tropical Atlantic and the variability of precipitation during the last millennium.

Referee Commentary

The method part, especially the LFCA method, needs to be described and reformulated in more detail. At the moment it is just an incorrect/incomplete copy and paste from the homepage where you can download the corresponding programs.

Response:

This is the new description of LFCA in the new pre-print:

The LFCA is a method used to identify patterns with a maximum ratio of low-frequency to total variance in a dataset. It achieves this by transforming the leading Empirical Orthogonal Functions (EOFs) of the data and applying a low-pass filter. The resulting patterns, known as Low-Frequency Patterns (LFPs), and their corresponding components, called Low-Frequency Components (LFCs), represent the low-frequency variability in the data. The LFCA method, as described by Wills et al. (2018), enables the disentanglement of low-frequency signals from higher-frequency noise in a dataset. By isolating the low-frequency patterns, we can gain insights into the underlying dynamics and variability of the studied system on longer timescales. The LFCA technique can be valuable for understanding and analyzing climatic, as it helps identify and separate low-frequency variability patterns that may be associated with significant climate modes or long-term trends. To analyze the variability of the ITCZ associated with the LIA and the MCA, the LFCA was applied to SST and precipitation anomalies in the region between 30◦S and 30◦N. Additionally, the SST in the tropical Atlantic region was included in the analysis. The LFCA method was used to identify patterns with the highest ratio of low-frequency to total variance in the long-term simulations of SST and precipitation anomalies for the last millennium. Specifically, the monthly data of the ensemble, averaging the models MRI-ESM2-0 and MIROC-ES2L. By applying LFCA to the SST and precipitation anomalies, we aimed to uncover the low-frequency variability patterns associated with the ITCZ during the LIA and MCA periods. This analysis provides insights into how the ITCZ position and precipitation patterns varied during these climatic epochs.

Referee Commentary

Please make it clearer throughout the text which region regarding the ITCZ you mean. Depending on the case, in several instances it is not clear whether you mean the ITCZ in the Atlantic, in other regions, or as a zonal mean. Please be more specific, especially when referring to the literature.

Response:

We describe the study area in more detail:

The variability of SST in the Tropical Atlantic (TA) plays a significant role in influencing the precipitation regime, which has important implications for the populations of Africa and South America (Seager et al., 2010). In the NEB region, the SST of the TA and tropical Pacific oceans are considered the primary physical variables that contribute to climate variability conditions (Philander, 1989). Changes in these SST patterns can impact atmospheric circulation patterns and influence rainfall in NEB. In the Equatorial Atlantic (EA), the gradients of SST towards the southern latitudes have a significant influence on the total precipitation in the NEB region. These SST gradients play a crucial role in modulating the latitudinal positioning of the ITCZ, which is a key driver of rainfall patterns. Changes in the SST gradients in the EA can result in shifts in the position of the ITCZ, thereby impacting the distribution and intensity of precipitation in NEB (Hastenrath and Greischar, 1993; Hastenrath, 1984; Nobre and Shukla, 1996; Marengo, 2004; Chang et al., 2006; Marengo et al., 2017; Deser et al., 2010). In response to the warming of SST in the Atlantic and the variability in the intensity of the trade winds, the ITCZ presents a latitudinal displacement throughout the year (Waliser and Gautier, 1993; Waliser and Jiang, 2015). The changes in SST and trade winds can influence the atmospheric circulation patterns, leading to a movement of the ITCZ and consequently impacting the distribution of rainfall in different regions. Between February and March, the ITCZ is typically located between the equator and around 5°N in response to specific atmospheric and oceanic conditions. During this period, the South Atlantic experiences higher SST, which contribute to the northward displacement of the ITCZ. Additionally, the northeast trade winds intensify during the austral summer, further influencing the latitudinal positioning of the ITCZ. These factors combined result in the ITCZ being situated in the specified latitude range during this time of the year. Between July and August, the ITCZ tends to be located approximately between 5°N and 8°N in the western part of the TA. This positioning is influenced by several factors. Firstly, the North Atlantic experiences higher SST during this period, contributing to the northward displacement of the ITCZ. Additionally, the high-pressure centers in the Azores and St. Helena regions become more prominent, leading to the intensification of southeast trade winds and a weakening of the northeast trade winds. (Peterson and Stramma, 1991; Wagner, 1996; Hastenrath, 2006). Seasonal migration of the ITCZ is the main mechanism that induces precipitation in the TA region (Hastenrath and Greischar, 1993) and variations in its migration are related to SST anomalies in the TA. The meridional variability in the tropical Atlantic Ocean is known as the Atlantic Meridional Mode (AMM). The AMM is a mode of climate variability in the tropical Atlantic Ocean. It refers to the meridional gradient (north-south) of sea surface temperature anomalies between the northern and southern tropical Atlantic. In NEB, the ITCZ is considered the dominant factor influencing precipitation patterns. When the ITCZ is located over NEB, it brings moist air and favorable conditions for precipitation. Conversely, when the ITCZ shifts away from NEB, drier conditions prevail. Thus, the variability and movement of the ITCZ are essential for understanding and predicting precipitation patterns in this region (Hastenrath and Heller, 1977; Hastenrath, 1997; Hastenrath and Lamb, 1977).

Referee Commentary

I wonder if the data from the last millennium simulations are from just two models available. The variables - like slp, precipitation, winds, omega - seem to be very basic model outputs.

Response:

We update the text and table:

The model evaluation was based on historical simulations of CMIP5 and CMIP6 models, as shown in Table 1. The main objective was to quantitatively assess the estimation of the variability of the ITCZ in the tropical Atlantic. The first analysis aimed to compare the average annual rainfall cycles simulated by the CMIP5 and CMIP6 models with the observed pattern (GPCP). The Last Millennium (LM) experiments, designed to contribute to the Coupled Model Intercomparison Project Phase 6 (CMIP6) as described by Eyring et al. (2016), have been incorporated into the Paleoclimate Modelling Intercomparison Project Phase 4 (PMIP4). These simulations encompass the period from 850 to 1850. The model's data can be downloaded from the following URL: https://esgf-node.llnl.gov/search/cmip6. We utilized the LM outputs from two models: MIROC-ES2L (Hajima et al., 2019) and MRI-ESM2-0 (Yukimoto et al., 2019). These models were chosen specifically because they were the only ones that provided data for all five climatic variables considered for the last millennium period (850 – 1850 AD). For our study, we specifically chose the first and second realizations of the MIROC-ES2L and MRI-ESM2-0 models (designated as r1i1p1f2 and r1i1p1f1, respectively). These selections were made due to the unavailability of the first realization in these models. The monthly scalar variables used in our analysis include precipitation (PR), sea surface temperature (SST), zonal and meridional wind components (u and v), and the Lagrangian tendency of air pressure (ω).

Table 1. List of outputs from the CMIP5 and CMIP6 models used in this study.

N°	INSTITUTION	CMIP5	Atmospheric grid (lat.×lon.)	CMIP6	Atmospheric grid (lat.×lon.)
1	Meteorological Research Institute (MRI)	MRI-ESM1	1.1°× 1.1°	MRI-ESM2-0**	1.1°× 1.1°
2	Atmosphere and Ocean Research Institute (AORI)	MIROC-ESM	2.8°× 2.8°	MIROC-ES2L*	2.7°× 2.8°
3	National Aeronautics and Space Administration (NASA)	GISS-E2-H	2.0°× 2.5°	GISS-E2-1-G	2.0°× 2.5°
4	Met Office Hadley Centre	HadCM3	3.7°× 2.5°	HadGEM3-GC31-LL	1.25°× 1.87°
5	Institut Pierre-Simon Laplace (IPSL)	IPSL-CM5A-LR	1.9°× 3.8°	IPSL-CM6A-LR	1.3°× 2.5°
6	Max Planck Institute for Meteorology (MPI-M)	MPI-ESM-P	1.9°× 1.9°	MPI-ESM1-2-LR	1.87°× 1.87°
7	Beijing Climate Center (BCC) and China Meteorological Administration (CMA)	BCC-CSM-1-1-m	2.8°× 2.8°	BCC-CSM2-MR	1.1°× 1.1°
8	Atmosphere and Ocean Research Institute (AORI)	MIROC5	1.4°× 1.4°	MIROC6	1.4°× 1.4°
9	Australian Community Climate and Earth System Simulator (ACCESS)	ACCESS1-0	1.3°× 1.9°	ACCESS-CM2	1.2°× 1.8°

Note: the resolution of the historical ensemble is 2.5°× 2.5°. While CMIP6 averages for the last millennium have a resolution of 1.1°× 1.1°. Model vegetation distribution *natural and **prescribed.

Referee Commentary

I am not familiar with the LFCA method. But I wonder a bit about the results shown in Figures 10 and 11. If I understand correctly, the LFCA was calculated separately for the MCA and LIA periods. If the spatial patterns were robust, I would expect that the patterns during the MCA and LIA periods should be the same, probably in a different order (explained variance). Some patterns seem similar, but most are different. Is this an indication that the spatial patterns are not stable/robust? Or are there, not a few dominant patterns, so the patterns change position/explained variance easily? I think it should be checked if the individual patterns are stable and clearly separated.

Response:

If indeed the LFCA was calculated separately for the MCA and the LIA. In LFP 1 (Figures 10a and b), it can be observed that during the LIA, the central-east region of Brazil exhibits wetter conditions compared to the MCA. This is associated with a strengthening of the SAMS, with the South Atlantic being warmer than the North Atlantic (Figures 11a and b). During the MCA, the NEB is wetter than during the LIA, suggesting a strengthening of the ITCZ. Additionally, it can be observed that the SACZ band extends to the Atlantic Ocean region adjacent to southeastern Brazil (Figures 10a and b). This precipitation distribution pattern was observed by Viana et al. (2014), who suggest that during the MCA, the Boqueirão Lake was wet due to the southward displacement of the ITCZ during the negative phase of the AMO. In contrast, during the LIA, dry periods occurred due to the intensification of the Northeast High during an intense period of the SAMS. In LFP 2 (Figure 10c), wet conditions are observed in the Cariaco Basin and dry conditions in the Boqueirão Lake during the MCA, despite lower SST. This differs from the expected conditions for the MCA in the northern hemisphere (Figure 11c). This pattern was observed by Novello et al. (2012), who described arid conditions in the southern part of the NEB, attributed to the northward displacement of the ITCZ and the weakening of the SACZ. During the LIA, higher humidity is observed in Boqueirão with higher SST in the tropical South Atlantic (Figure 11d), and southward migration of the ITCZ is recorded (Figure 10d). This pattern was also shown by Haug et al. (2001); Peterson and Haug (2006); Vuille et al. (2012); Lechleitner et al. (2017). In LFP 3, during the MCA, precipitation is distributed along the South American Atlantic coast, and both the Cariaco Basin and the Boqueirão Lake exhibit wet conditions (Figures 10e and f). Additionally, SST is warmer throughout the tropical South Atlantic (Figures 11e and f). On the other hand, during the LIA, the easternmost part of the NEB is wetter (Figure 10f), and precipitation is observed along the Amazonian coast. The SST variation between the northern and southern Atlantic is smaller, but it remains warmer in the south (Figures 11e and f). In LFP 4, an increase in precipitation is observed in the northernmost part of the NEB during the LIA period compared to the MCA (Figure 10h and g). However, in both periods, the tropical North Atlantic exhibits higher SST conditions (Figure 11g and h). The Cariaco area shows wet conditions during the LIA, which contradicts the observations made by paleoclimatic proxies (Haug et al., 2001).

Through the analysis, we were able to observe the preference modes of the ITCZ: On interannual to decadal timescales, the coupling between the atmosphere and the ocean plays a crucial role. Our findings indicate that the north-south displacement of the ITCZ is strongly related to the oceanic region exhibiting the highest SST within the South Atlantic tropical basin. The variability of the zonal mode is mainly associated with the equatorial region, extending between 5◦S and 5◦N, as well as the northwest coast of Africa. These observations also contrast with paleoclimatic records of the region, indicating a northward displacement of the ITCZ during the MCA and a southward displacement during the LIA. During the LIA, the southward displacement of the ITCZ is a response to the relative cooling of the Northern Hemisphere due to volcanic forcing. This highlights the complex interaction between solar forcing and atmospheric dynamics in shaping the behavior of the ITCZ during the LIA.

Additionally, the 21-year periodicity associated with the solar cycle is predominant during the Last Millennium. This influences the pattern of tropical rainfall and favors a contraction and southward displacement of the ITCZ towards the equator. The changes in the position of the ITCZ during the last millennium are influenced by internal forcings such as ENSO, PDO, and AMO, which exhibit spatial patterns of latitudinal displacement between northern and southern regions. These internal modes of variability can interact and influence the position and intensity of the ITCZ, thus affecting regional climate variability. According to these observations, during the positive phase of the AMO, we observed a northward meridional displacement of the ITCZ. On the other hand, during the negative phase of the AMO, we observed a southward meridional displacement of the ITCZ. The results suggest the existence of low-frequency variability, modifying the distribution of precipitation and having consequences on the intensity and frequency of drought/flood events in the NEB. These findings indicate that these events are associated with ocean-atmosphere coupling.

Minor comments:
Not all abbreviations are explained, at least not the first time they are used.
Response:
abbreviations have been corrected

Title and text: make more clear that you refer to the ITCZ in the Atlantic region
Response:
Yes

In line 78: Models can be downloaded => Data of the model simulations can be downloaded
Response:
Yes

Rephrase the title; at the moment, it reads like two unrelated clauses.
Response:
Yes

Line 112, line 341: AT=> TA?
Response:
Yes

Please define the tropical Atlantic (TA) region precisely, in particular the longitudes – because it seems that you have also used precipitation over land (not ocean restricted).
Response:
we add the limits in the study area (30N to 30S and 80W to 20E)

Line 197: Fig.2 => Fig.4 ?
Line 237: p eriod => period
line 360, 363, 372: blank missing
Response: This was fixed