**Comment on egusphere-2022-785**
Anonymous Referee #2

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**
Authors have investigated low frequency components of decadal-multidecadal ITCZ variability in the Last Millennium experiment and compared results with some proxy. They found a meridional mode coherent with ITCZ migration and a zonal mode associated with east-west shift of precipitation in the Atlantic. Authors have linked the 21-year periodicity to solar cycle superimposed to longer periodicity. The manuscript is so poorly written that is almost impossible to go through results. The rational structure is not clear as well as the main goal of the paper. Methods are also poorly described and the overall text seems a collection of this and that without focus. I encourage the authors to carefully revise the text putting particular emphasis on the English.

**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**
Abstract

**Ln 7:** what is MCA? Acronyms not spelled before.
**Response:** Medieval Climate Anomaly (MCA), was corrected in the new version of pre-print.

**Ln 8:** LIA as well... I guess it is Little Ice Age, but for many people in the field not focused on paleoclimate, this needs to be spelled it out.
**Response:** Little Ice Age (LIA), was corrected in the new version of pre-print.

**Ln 8-10:** The sentence needs some rephrasing. Please consider the following rephrasing.
"Based on our results, the 21-year periodicity associated with solar cycle is predominant during the Last Millennium. It influences the tropical rainfall pattern and favors a contraction and an equatorward shift of the ITCZ."
**Response:**
We have considered your suggestion, and the modified phrase can be found on line 9.
According to our results, the 21-year periodicity associated with the solar cycle is predominant during the Last Millennium. This influences the pattern of tropical rainfall and promotes a contraction and southward displacement of the ITCZ.

**Ln 18:** remove [meet and], replace [maxima] with [peak].
**Ln 20:** dynamic -> dynamics
**Response for both:**
the abstract was modified:
Decadal and multidecadal variability of the Intertropical Convergence Zone (ITCZ) in space-time is analyzed using CMIP5 and CMIP6 simulations and paleohydrological records from the Last Millennium. The persistence patterns of the CMIP6 ensemble models were investigated, employing the Low-Frequency Component Analysis (LFCA) to isolate the mechanisms that modulate the multidecadal-scale behavior of the ITCZ. The results suggest that the north-south displacement of the ITCZ is related to the oceanic region with the highest Sea Surface Temperature (SST) in the tropical South Atlantic basin. The zonal mode variability is primarily associated with the equatorial region (between 5$\degree$S and 5$\degree$N) and the northwest coast of Africa. These observations are consistent with the paleoclimatic records of the region, which indicate a northward displacement of the ITCZ during the Medieval Climate Anomaly (MCA, 900 -- 1150 AD) and a southward displacement during the Little Ice Age (LIA, 1500 -- 1850 AD). According to our results, the 21-year periodicity associated with the solar cycle is predominant during the Last Millennium. This influences the pattern of tropical rainfall and promotes a contraction and southward displacement of the ITCZ. These changes in the position of the ITCZ are influenced by internal forcings such as El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multidecadal Oscillation (AMO), which exhibit spatial patterns of latitudinal displacement between the northern and southern regions. These internal modes of variability can interact and influence the position and intensity of the ITCZ. The results suggest the existence of low-frequency variability that modifies the distribution of precipitation and has consequences for the intensity and frequency of drought/flood events in Northeast Brazil (NEB), indicating that these events are associated with the coupling between the oceans and the atmosphere.

**Ln 20 – 34:** please revisit the literature considering the energy framework described in:

1. Broccoli, A. J., K. A. Dahl, and R. J. Stouffer, 2006: Response of the ITCZ to northern hemisphere cooling. Geophysical Research Letters, 33, L01702, doi:10.1029/2005GL024546.
2. Boos, W. R., & Korty, R. L. (2016). Regional energy budget control of the intertropical convergence zone and application to mid-Holocene rainfall. Nature Geoscience, 9(12), 892-897.
3. Marshall, J., A. Donohoe, D. Ferreira, and D. McGee, 2013: The ocean's role in setting the mean position of the atmosphere's ITCZ. Climate Dynamics, 42, 1967–1979, doi:10.1007/s00382-013-1767-z.
4. Donohoe, A., J.Marshall, D. Ferreira, andD.McGee, 2013: 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, doi:10.1175/JCLI-D-12-00467.1.

**Response:**
References 1 and 2 were added in lines 24 to 34:

Observations suggest that the interannual variability of the Atlantic ITCZ position is influenced by the Sea Surface Temperature (SST) for the tropical Atlantic and the tropical Pacific Ocean (Nobre and Shukla, 1996; Giannini et al., 2001; Chiang et al., 2002; Tedeschi et al., 2013). Indeed, several studies have attempted to understand the response of the meridional position of the ITCZ to past changes and the potential changes it may undergo in the future (Chiang and Bitz, 2005; Broccoli et al., 2006; Boos and Korty, 2016; Byrne et al., 2018).

Reference 3 in lines 20 to 25:
The Intertropical Convergence Zone (ITCZ) is the most important meteorological system in the tropical region, and its Atlantic sector influences the precipitation and temperature patterns in the North and Northeast regions of Brazil. The ITCZ is a narrow band located near the equator where the trade winds from the north and south converge, creating cumulus clouds and generating maximum precipitation in these regions (Waliser and Gautier, 1993; Philander et al., 1996). The position, intensity, and dynamics of the ITCZ are the result of the coupling between the ocean-atmosphere and the ocean-land processes (Marshall et al., 2014)

Reference 4 in lines 45 to 47
Previous studies have used observations and climate model simulations to analyze the relationship between the position of the ITCZ and the energy flux. These authors demonstrated that the position of the ITCZ is highly anticorrelated with the strength of the zonal mean energy flux across the equator (Kang et al., 2008; Donohoe et al., 2013; D'Agostino et al., 2020).

**Referee Commentary:** In particular it is valuable for this study to connect shifts in the ITCZ with insolation and Net Energy Input at the equator.

1. D'Agostino, R., Brown, J. R., Moise, A., Nguyen, H., Dias, P. L. S., & Jungclaus, J. (2020). Contrasting southern hemisphere monsoon response: MidHolocene orbital forcing versus future greenhouse gas–induced global warming. Journal of Climate, 33(22), 9595-9613.

**Response:**
the reference was added in line 45
Previous studies have used observations and climate model simulations to analyze the relationship between the position of the ITCZ and the energy flux. These authors demonstrated that the position of the ITCZ is highly anticorrelated with the strength of the zonal mean energy flux across the equator (Kang et al., 2008; Donohoe et al., 2013; D'Agostino et al., 2020).

**Ln 42:** what is Neotropics?
**Response:**
The correct word is tropics. It was corrected in the new version of the pre-print.

**Ln 56:** what is NEB? Please check that every acronyms have been spelled before invoking them!

**Response:**
It was corrected in the new version of the pre-print.

**Ln 55 – 70.** Please revisit the mechanisms accounting for energy variations instead focusing on Sea Surface Temperature anomalies.
**Response:**
We include your suggestion between lines 29 - 48:
Observations suggest that the interannual variability of the Atlantic ITCZ position is influenced by the Sea Surface Temperature (SST) for the tropical Atlantic and the tropical Pacific Ocean (Nobre and Shukla, 1996; Giannini et al., 2001; Chiang et al., 2002; Tedeschi et al., 2013). Indeed, several studies have attempted to understand the response of the meridional position of the ITCZ to past changes and the potential changes it may undergo in the future (Chiang and Bitz, 2005; Broccoli et al., 2006; Boos and Korty, 2016; Byrne et al., 2018). These studies utilize climate models and paleoclimate data to investigate the mechanisms and factors influencing the meridional displacement of the ITCZ under different climate conditions. By examining past climate variations and considering future climate projections, scientists aim to improve our understanding of the complex dynamics driving the position of the ITCZ and its potential implications for regional and global climate patterns. However, the north-south displacement of the ITCZ exhibits interannual variability, as shown by Uvo (1989). Their results showed that the ITCZ exhibits a southward displacement during the rainy season over the NEB, specifically over the northern part of this region. It has also been observed that in dry years, the ITCZ starts shifting northward in late February or early March, while in rainy years, the shift occurs in late April or early May (Uvo, 1989). For example, Marshall et al. (2014) studied the role of the ocean in determining the average position of the ITCZ. The authors found that the average position north of the equator is a result of heat transport northward by ocean circulation. Broccoli et al. (2006) used coupled models to study the response of the ITCZ to a cooling forcing in the Northern Hemisphere. They found that cooling in the North Atlantic was responsible for changing the structure of the northern branch of the Hadley cell, expanding and intensifying it, and causing a southward displacement of the ITCZ. Previous studies have used observations and climate model simulations to analyze the relationship between the position of the ITCZ and the energy flux. These authors demonstrated that the position of the ITCZ is highly anticorrelated with the strength of the zonal mean energy flux across the equator (Kang et al., 2008; Donohoe et al., 2013; D'Agostino et al., 2020).

**Ln 69:** what is the difference between Atlantic Meridional Mode and Atlantic Multidecadal Oscillation or Variability? Can you indicate typical latitudes or periodicities?
**Response:**
The Atlantic Multidecadal Oscillation (AMO) and the Atlantic Meridional Mode (AMM) are both climate patterns associated with the Atlantic Ocean, but they represent different phenomena (line 55). The AMO is a climate oscillation characterized by long-term variations in SST in the North Atlantic Ocean, while Atlantic Meridional Mode (AMM) or Atlantic Meridional Dipole (AMD) is a mode of climate variability in the tropical Atlantic Ocean (line

135). This index is associated with changes in the intensity and position of the Intertropical Convergence Zone (ITCZ)

**Table 1:** you can indicate the resolution for each model and CMIP phase and eventually indicate if the model has prescribed/dynamic vegetation.
**Response:**
we add the resolution of each of the models and vegetation distribution for the models using for the last millennium.

**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.

**Subsection 4.1:** it might be beneficial for the paper including also a brief discussion about the modelled onset and withdrawn of South American monsoon (specifically for North Eastern Brazilian precipitation) that might be delayed given the bias in DJF – MAM with GPCP of the Atlantic ITCZ to which it is strictly connected. The whole section is poorly Written.
**Response:**
Your suggestion for a SAMS discussion was included in section 4.1. (from line 245)

**Ln 140:** “Probabilistic The location of the ITCZ”: there must be a typo somewhere.
**Response:**
That section was changed to “Latitudinal Position of the ITCZ”.

**Ln 144-145:** “Our results indicate that the CMIPs models simulate a migration of the ITCZ towards the south in relation to those observed in the DJF and MAM periods.” To those what? Not clear this sentence to me. And afterwards “Atlantic bias greater relative to …” than what? Are your referring to a spatial or temporal comparison??? Not clear and additionally check the English please.
**Response:**
For the period of 1981-2005, during the austral summer and autumn seasons (DJF and MAM), our results indicate that the CMIP models estimate the position of the ITCZ with a marked southward inclination in its displacement. Figure 1 shows a seasonal bias in the position of the ITCZ compared to the observed data, where this difference has a greater magnitude during the DJF and MAM seasons. Since, for these seasons, the results for GPCP show a predominant position of the ITCZ north of the equator (Figure 1c). This finding

contrasts with recent studies highlighting the limitations of CMIP models in simulating the position and intensity of the ITCZ (Richter and Xie, 2008; Richter et al., 2012; Zermeño-Diaz and Zhang, 2013; ?; Mamalakis et al., 2021). These model biases could also be related to the parameterization of atmospheric and oceanic processes (Zhang et al., 2019; Song and Zhang, 2020). Mamalakis et al. (2021) found that CMIP models underestimate the interannual variability of the position of the ITCZ in the tropical Atlantic, suggesting that models may have difficulty capturing the dynamic processes that modulate the position of the ITCZ in this region.

Hwang and Frierson (2013) also studied this pattern, highlighting that the issue of the double ITCZ in models is due to the bias in the energy balance between the two hemispheres. Furthermore, they observed that the excess energy absorbed in the southern hemisphere was transported to the northern hemisphere through the upper branch of the anomalous Hadley cell over the equator. Meanwhile, the lower branch transported water vapor southward, causing a southward displacement of the ITCZ and inducing the formation of the double ITCZ. Adam et al. (2016) suggest that CMIP5 models exhibit a positive bias in atmospheric energy transport, which can lead to a shift in the formation of the double ITCZ. This bias could be related to errors in the representation of physical processes and atmospheric interactions in the models, resulting in an inadequate simulation of the ITCZ and its variability patterns. In general, models tend to exhibit a bias over the tropical Atlantic, overestimating the probability of the ITCZ migrating southward (Figure 1)

**Ln 180:** title of section 4.2: something weird in “The Interdecadal Component temporal of the ITCZ latitudinal location” -> check the English: remove temporal!
**Response:**
Yes, we consider your suggestion (The Interdecadal Component of the ITCZ latitudinal location)

**Ln 181:** Furthermore, replace “this study isolates” with “this section is focused on”.
**Ln 181-182:** “Our analysis identifies the multidecadal Atlantic SST variability over the
**Response:**
This study isolates multidecadal variability on precipitation and the Atlantic sea surface temperature by using low-frequency component analysis (LFCA). Our analysis identifies the multidecadal Atlantic SST variability over the subpolar North Atlantic. To investigate latitudinal ITCZ displacements, we compare the data from Boqueirão Lake to the Ti record from Cariaco Basin; these southern variations of the ITCZ could be marked by the antiphasic relationship with the Cariaco Basin. There was evidence of migration from the ITCZ further south in relation to its current position. In general, the results of the LFCA analysis indicate that the SST and precipitation variables of the ensemble (Averaging the models MRI-ESM2-0 and MIROC-ES2L) in the last millennium are capable of reproducing the large-scale changes in the location of the ITCZ in the Atlantic and the precipitation during the LIA and MCA periods, these results are consistent with the evidence from the paleoclimatological records.

Ln 190: what is deltaDwax?

**Response:**

The hydrogen isotope composition of the n-C28 alkanoic acid (δD wax )

Ln 196: what is %Ti?

**Response:**

Titanium percent

**Results and discussion section:**

I found the entire discussion of Results poorly written. It is very hard to follow. The section contains too many acronyms. Somehow also how the results are structured is confusing. I strongly recommend to rewrite the section being more rational in the way the results are described.

**Response:**

Indeed, we have a new manuscript following all the indications provided.