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Influences of strong and moderate ENSO events on the Maranhão precipitation from the western equatorial Atlantic SST anomalies

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ABSTRACT

This study analyzed the influence of strong and moderate El Niño-Southern Oscillation (ENSO) events on the seasonal and interannual variabilities of the sea surface temperature (SST) in the Western Equatorial Atlantic (WEA) Ocean and how the precipitation over the state of Maranhão, in Brazil, responds to the zonal teleconnection. To evaluate the ENSO magnitude and phase in the four Niño regions (1+2, 3, 3.4, and 4), the SODA 3.3.1 oceanic reanalysis database for the period from 1980 to 2015 was used. Our results showed that the La Niña phase with moderate magnitude was the most predominant among the 70 events analyzed, with Niño 3.4 presenting the highest number (20) of ENSO events (both positive and negative phases). At lag = 0, we found that significant negative correlations prevailed between the WEA SST anomalies and ENSO index, with the region of Niño 3.4 showing the most significant correlations ($r = -0.25$). The whole events of El Niño and La Niña were, respectively, accompanied by a cooling and a heating of up to −0.6°C or +0.8°C in the WEA Ocean. The WEA SST anomalies during El Niño and La Niña events have, respectively, reduced and increased the precipitation in Maranhão around ± 100 mm in a quarter. Strong El Niño events influence a greater precipitation deficit in Maranhão than moderate El Niño events. Moderate La Niña events have more pronounced influence on the precipitation over Maranhão than strong La Niña events do, especially on the negative anomalies. Our results showed that the central, northern, and eastern tip sectors of the state are the most affected by this zonal teleconnection. We concluded that ENSO's significant influences on the WEA SST seasonal variability, added to the performance of the Atlantic Meridional Mode (Soares 2019), determine the quality of the rainy season (March–April–May) in the state of Maranhão.

Keywords: El Niño, Interannual Variability, Zonal Teleconnection, Maranhão Climate, Precipitation Variability

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INTRODUCTION

The El Niño-Southern Oscillation (ENSO) is the main variability mode of the global coupled climate system (Cai et al., 2020), being configured by sea surface temperature (SST) anomalous patterns in the central-east Equatorial Pacific Ocean, with El Niño and La Niña characterizing, respectively, the warm and cold phases, with warming and cooling over this region. The oceanic component of ENSO is associated with anomalous sea level pressure (SLP) patterns in the Indo-Pacific region (Trenberth, 1984) that lead to precipitation extremes in several regions of the globe, such as South America (Carton et al., 1996; Stone et al., 1996; Fontana and Berlato, 1997; Andreoli et al., 2016; Cabos et al., 2019). Some studies have shown that ENSO influences significantly the interannual variability of the Tropical Atlantic (TA) Ocean (Saravanan and Chang, 2000; Münnich and Neelin, 2005; Rodrigues et al., 2011; Rodríguez-Fonseca et al., 2016; Lübbecke et al., 2018). The three main regions influenced by the ENSO are the North Tropical Atlantic (NTA), the Equatorial Atlantic, and the South Tropical Atlantic (STA) (Enfield and Mayer, 1997; Huang et al., 2004).

Associated with the seasonal cold tongue development, the Atlantic Equatorial Mode, also known as Atlantic Niño due to its similarity with ENSO, is a dominant mode of interannual variability in the TA region (Servain et al., 1982, 1999; Zebiak, 1993; Chang et al., 2006; Lübbecke and McPhaden, 2012). The Atlantic Equatorial Mode has been recognized since the 1980's (Merle et al., 1980; Servain et al., 1982; Hirst and Hastenrath, 1983; Philander, 1986). According to Hounsou-Gbo et al. (2020), there are two types of Atlantic Niño, which are significantly anti-correlated with ENSO and quite relevant for its predictability from 6 months to 1 year.

One of the mechanisms for climate signal transfer from the Pacific to the Atlantic basin occurs in the tropics through zonal SLP and wind anomalies associated with the Walker and Hadley cells (Kidson, 1975; Zhou and Lau, 2001; Nogues-Paegle et al., 2002). The zonal teleconnection is modified, via Walker circulation, during the El Niño condition, then the tropical convection in its ascending branch shifts to the east, towards the central–eastern Pacific. Its descending branch also migrates eastwards, eventually inhibiting the convection over the Equatorial Atlantic and the Northeast region of Brazil (NEB), establishing drought conditions during its rainy season (March–April–May) (Hastenrath and Heller, 1977; Grimm and Ambrizzi, 2009; Grimm, 2011; Rodrigues et al., 2011; Cai et al., 2020; Hounsou-Gbo et al., 2020). Conversely, during the La Niña phase, the SST of the STA is heated more (Covey and Hastenrath, 1978; Hastenrath et al., 1987), resulting in the southward shift of the Intertropical Convergence Zone (ITCZ), enhancing the rainy season in the NEB (Hastenrath and Heller, 1977; Grimm, 2011; Cai et al., 2020). Thus, changes in the magnitude and position of ITCZ during ENSO events significantly modulate the precipitation distribution in the NEB and North region, with distinct characteristics between its phases (Münnich and Neelin, 2005; Grimm and Tedeschi, 2009; Kayano et al., 2016; Tedeschi et al., 2016).

Periods of severe droughts related to ENSO events were recorded in states of NEB, such as Ceará, Pernambuco, and Paraíba, where the precipitation anomalies showed a better correlation with the SST anomalies that occurred in STA than in NTA (Cerqueira, 2010; Rodrigues et al., 2011; Braga et al., 2014). By considering an index derived from an empirical relationship that incorporates the effects of drought-induced senescence, Cunha et al. (2018) showed that strong El Niño-related droughts were spatially limited to the northern sector, covering only around 30% of the NEB. Thus, severe drought events are not only associated with the occurrence of ENSO, but also with certain oceanic and atmospheric configurations in the TA Ocean, such as warmer SST anomalies in the NTA and colder SST anomalies in the STA (Alves et al., 2009; Hounsou-Gbo et al., 2016), that shift the ITCZ northwards (Rodrigues and McPhaden, 2014). Extreme precipitation events majorly impact human activities, affecting important sectors of society such as agriculture and energy generation. In view of the accelerating regional and local climate changes in response to the global warming trend, this article aims to analyze the influence of strong and moderate ENSO events on the seasonal and interannual SST variability of the Western Equatorial Atlantic (WEA) Ocean, focusing on the potential impacts over the precipitation regime in the state of Maranhão.

DATA, METHODS, AND ANALYZES

SST AND PRECIPITATION DATA

The SST monthly averages from the Simple Ocean Data Assimilation (SODA, version 3.3.1) oceanic reanalysis database were used (Carton and Giese, 2008), with horizontal resolution of 0.25° x 0.25° (28 km at the Equator) and 50 vertical levels, for the period from January 1980 to December 2015. This reanalysis used the ocean component of the Geophysical Fluid Dynamics Laboratory's coupled climate model (GFDL/CM2.5), which includes an active sea ice component.

The SST monthly averages were obtained for Niño 4 (5°N–5°S; 160°E–150°W), Niño 3.4 (5°N–5°S; 170°W–120°W), Niño 3 (5°N–5°S; 150°W–90°W), Niño 1+2 (0°–10°S; 90°W–80°W), and WEA (10°N–10°S; 60°W–20°W) regions, as was also proposed by Soares (2019) (Figure 1). Based on these data, quarterly SST average anomalies (SSTA) were calculated to generate climate indices for each Niño region and then to build the climate composites for the WEA region.

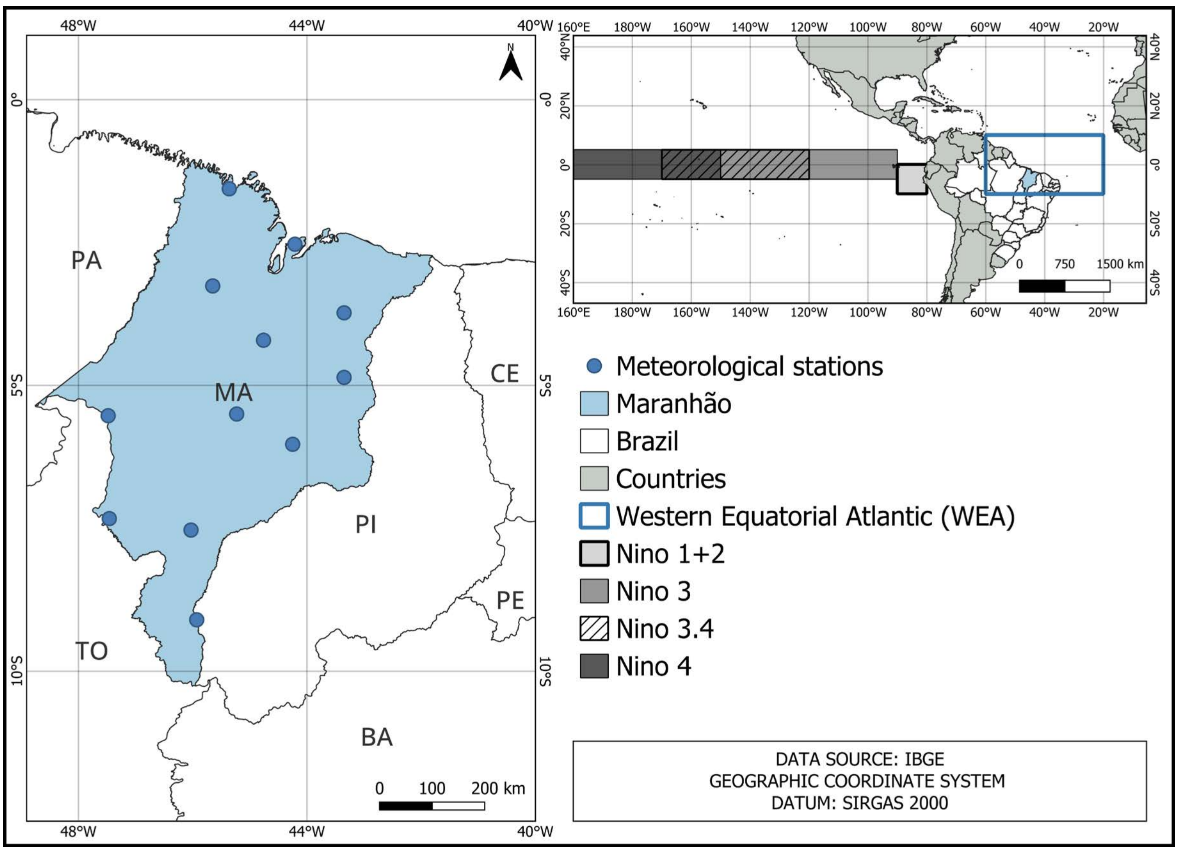

Figure 1. Spatial domain of the Western Equatorial Atlantic (WEA) Ocean and Niño regions, location of the state of Maranhão and the meteorological stations.

Observational monthly precipitation data of Maranhão were obtained from the Meteorological Database for Teaching and Research (BDMEP) elaborated by the National Institute of Meteorology (INMET), comprising the years from 1980 to 2015, available at www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. The data were obtained for the 12 automatic meteorological stations located in the state: Alto Parnaíba, Bacabal, Balsas, Barra do Corda, Carolina, Caxias, Chapadinha, Colinas, Imperatriz, São Luís, Turiaçu, and Zé Doca (Table 1, Figure 1).

Table 1. Location and altitude of the INMET meteorological stations in the state of Maranhão used in this study.

Locations	Latitude	Longitude	Altitude (m)
Alto Parnaíba	9.1°S	45.93°W	285.05
Bacabal	4.21°S	44.76°W	25.07
Balsas	7.53°S	46.03°W	259.38
Barra do Corda	5.5°S	45.23°W	153.00
Carolina	7.33°S	47.46°W	192.83
Caxias	4.86°S	43.35°W	103.56
Chapadinha	3.73°S	43.35°W	103.50
Colinas	6.03°S	44.25°W	179.75
Imperatriz	5.53°S	47.48°W	123.30
São Luís	2.53°S	44.21°W	50.86
Turiaçu	1.56°S	45.36°W	44.06
Zé Doca	3.26°S	45.65°W	45.28

Oceanic Niño Index calculation and its correlations with the WEA SSTA

The Oceanic Niño Index (ONI) in the Equatorial Pacific Ocean was computed from the quarterly SST average anomalies (SSTA, in °C) (quarterly average with 1-month moving window, i.e., DJF, JFM, FMA, …) for each Niño region (1+2, 3, 3.4, and 4), separately. For obtaining the SSTA, we calculated the quarterly averages for each year separately, and the total quarterly averages considering the entire period analyzed (1980–2015). From the quarterly average for each year (e.g., DJF of 1985) the total average of this quarter was subtracted (e.g., DJF), thus leading to the quarterly average anomaly for DJF. The SSTA were normalized and divided by their standard deviations to compare different Niño regions. An event was classified as El Niño or La Niña when the SSTA reached the threshold of ± 0.5°C (positive for El Niño and negative for La Niña) and persisted for a minimum of five consecutive seasons. The ONI was used to classify ENSO events according to their phases and intensities (see Table 2) as moderate El Niño (1.0 ≤ SSTA < 1.5°C) and strong El Niño (SSTA ≥ 1.5°C), moderate La Niña (−1.0 ≥ SSTA > −1.5°C) and strong La Niña (SSTA ≤ −1.5°C), based on thresholds predicted by the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA, 2019a, 2019b). Events considered weak were not analyzed in this study.

Pearson's linear correlation coefficient (Press et al., 1992) was calculated based on the time series of climate indices between the different Niño (1+2, 3, 3.4, and 4) and the WEA region, separately, considering the lag = 0. These were computed spatially with the view to determine the sectors with the highest correlations. As proposed by Sasaki (2014), the Pearson's correlation is here classified as strong ($r > 0.7$), from moderate to strong ($0.5 < r < 0.7$), moderate ($0.3 < r < 0.5$), and weak ($r < 0.3$).

Climate composites for WEA SST and Maranhão precipitation anomalies

To set up a teleconnection pattern between the central–eastern Equatorial Pacific and the WEA Ocean, total SSTA composites (spatial patterns) were constructed for the WEA region representative of the different phases (El Niño *vs* La Niña) and intensities (strong *vs* moderate). The total climate composites (considering all Niño regions in the analysis) were elaborated since at least one ENSO event has occurred in at least one of the Niño regions.

We created a numerical mesh to spatialize the INMET's meteorological stations precipitation data for the Maranhão state domain. Their boundary conditions were derived from the cartographic base of political limits of Brazilian states for the year 2006, provided by the Brazilian Institute of Geography and Statistics (IBGE). The coordinates were edited to obtain a single closed polygon, to carry out the steps of data extrapolation and interpolation for the Maranhão mesh grid (Furtado, 2019).

RESULTS AND DISCUSSION

Influences of ENSO phases and intensities on the WEA SSTA

Figure 2 shows the ONI calculated for the four Niño regions, separately. The most intense events of the positive phase of ENSO (El Niño condition) occurred in 1982–1983, 1997–1998, and 2015 in the Niño 1+2, Niño 3, and Niño 3.4 regions, with Niño 4 showing only the event of 2015. The Niño 3.4 had the highest number of most intense events, that is, 6 strong El Niño and 5 strong La Niña events (Figure 2b), followed by Niño 3, which had 4 strong El Niño and 4 strong La Niña events (Figure 2c). The Niño 1+2 region presented the largest positive SST anomalies for the two strongest El Niño events (1982–1983 and 1997–1998) that occurred during the period analyzed (1980–2015). Besides that, the highest number of moderate events occurred in this region, with 5 moderate El Niño and 8 moderate La Niña events (Figure 2d). Niño 4 had fewer events, which were classified as moderate and weak (Figure 2a). For the negative phase of ENSO (La Niña condition), the events that occurred in 2007 and 1988 were the most intense. In the La Niña event of 1988, the strongest negative SST anomalies have appeared in the Niño 3.4 region (Figure 2b), followed by the Niño 3 (Figure 2c). In the event of 2007, the most evident negative SST anomalies occurred in Niño 1+2 (Figure 2d), followed by the Niño 3 (Figure 2c). Compared with the other Niño regions, we found the Niño 3.4 and Niño 3 indices were the suitable reference of ENSO acting on the SSTA of the Pacific Equatorial region. According to Li et al. (2010), the Niño 4 index is not effective on tracking El Niño events since it can represent a joint performance of the El Niño classic and El Niño Modoki signals. This may explain the little information on ENSO events in the Niño 4 region (Figure 2a).

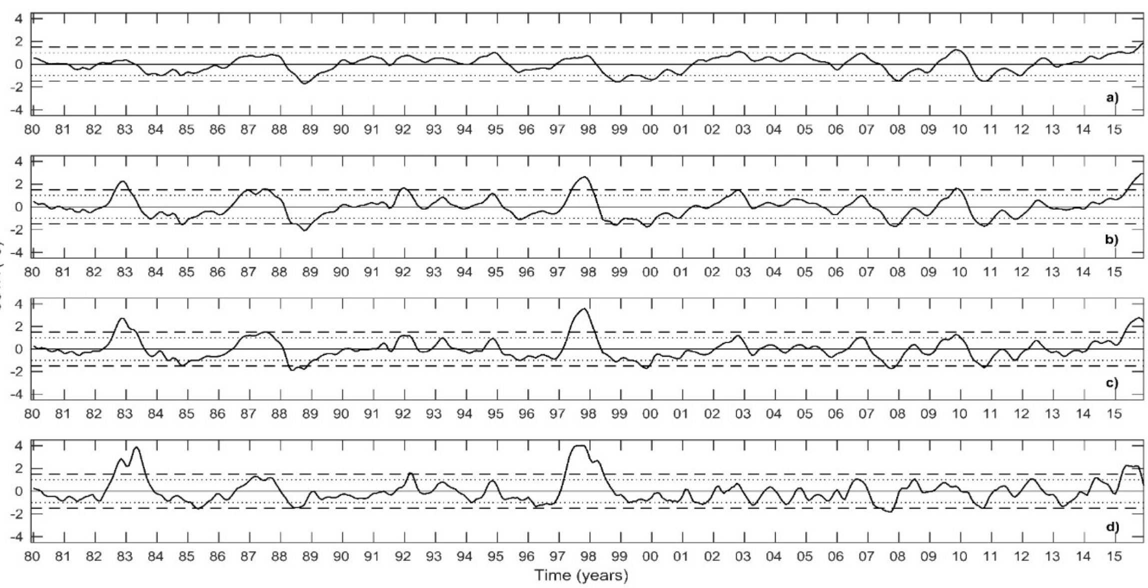

Figure 2. Oceanic Niño Index (ONI), from 1980 to 2015, based on quarterly SSTA of the SODA reanalysis (version 3.3.1) for the regions of: a) Niño 4; b) Niño 3.4; c) Niño 3; d) Niño 1+2. The dotted lines represent the thresholds for moderate events (± 1.0), whereas the dashed lines represent the thresholds for strong events (± 1.5).

The results show that the 36 years (from 1980 to 2015) analyzed had 13 strong events, with 6 El Niño and 7 La Niña events; and 27 moderate events, with 10 El Niño and 17 La Niña events (Table 2). To determine the Niño region with the greatest influence on the WEA SSTA variability associated with the zonal (Pacific–Atlantic) teleconnection, each ENSO phase was also classified according to its phase and intensity. The results showed that the Niño 3.4 region had the highest number of events (20 events), and the Niño 1+2 and Niño 3 regions had the same number of events (19 events in each region), although they have different phases and intensities. The Niño 4 region was the region with the lowest number of events (12 events) for the analyzed period (Table 2).

Table 2. Years of ENSO events from 1980 to 2015 classified according to its phase (El Niño *vs* La Niña) and intensity (strong *vs* moderate) in each Niño region (4, 3.4, 3, and 1+2).

	El Niño		La Niña	
	Strong	**Moderate**	**Strong**	**Moderate**
Niño 4	2015	1994, 2002, 2009	1988, 1998	1989, 1999–2000, 2007, 2008, 2010, 2011
Niño 3.4	1982–1983, 1987, 1992, 1997–1998, 2009, 2015	1986, 1994, 2002	1984, 1988, 1999, 2007, 2010	1985, 1989, 1995, 2000, 2008, 2011
Niño 3	1982–1983, 1987, 1997–1998, 2015	1986, 1991–1992, 2002, 2006	1988, 1999, 2007, 2010	1984–1985, 1989, 1995, 1998, 2000, 2008, 2011
Niño 1+2	1982–1983, 1992, 1997–1998, 2015	1987, 2006, 2008, 2012, 2014	1985, 2007	1988, 1996, 1999, 2001, 2003, 2004, 2010, 2013

The linear correlation computed between the ONI and the WEA SSTA has shown that this ocean exhibited spatially negative correlations ($r = -0.25$) with all Niño regions, mainly over the equatorial band and the STA basin (Figure 3). The higher and lower significant negative correlations were found between the SSTA in the WEA and Niño 3.4 and Niño 1+2, respectively. Significant negative correlations were also found near the west coast of Maranhão (Niño 3.4 and Niño 3) and near the capital of Maranhão (Niño 3.4 and Niño 4) (Figure 3). Positive weak correlations ($r = +0.1$) have been obtained for small areas, such as in NTA around 8°N and near the Northeast (Niño 1+2 and Niño 3) and the North (Niño 4) regions of Brazil.

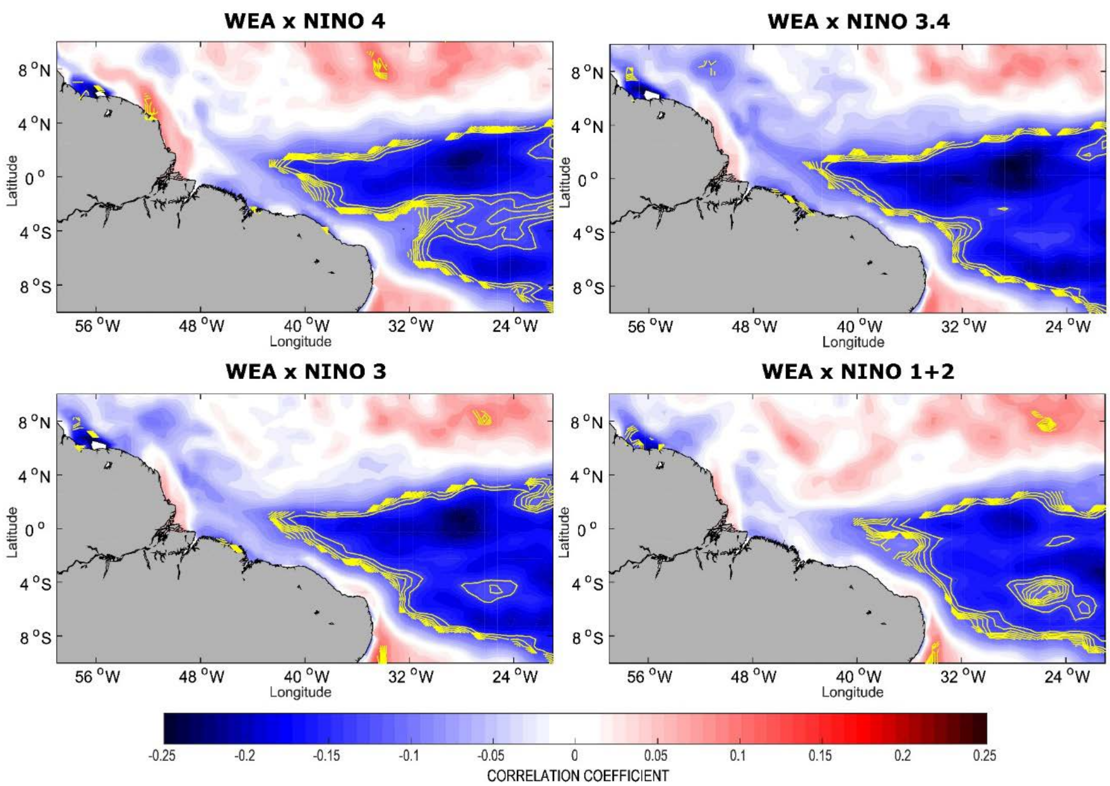

Figure 3. Correlation coefficients (lag = 0) between the SSTA in the Western Equatorial Atlantic (WEA) Ocean and in the Niño regions (4, 3.4, 3, and 1+2), separately. The yellow lines surround the statistically significant values at the 5% significance level ($p \leq 0.05$).

The weak significant correlation found between ENSO and WEA SSTA in this study corroborates the results found by Zebiak (1993), Enfield & Mayer (1997), and Rodrigues et al. (2011) who found a weak correlation between Niño 3 and the TA ocean. Despite the low correlation coefficients between ENSO and WEA at lag = 0 in this study, Soares (2019) has shown that, except for Niño 4, all correlations between ENSO and NTA/STA regions were significant at a 5% significance level. In the positive phase of ENSO, a positive SSTA is expected in the NTA oceans, with the highest correlation at lag = −5 and +5, and in the negative phase, a negative SSTA is expected in the STA oceans, with the highest correlation at lag = −5. According to this author, the highest lagged correlations have occurred between the NTA and STA and Niño 4 and Niño 3.4 regions, respectively. This result is consistent with those of Servain (1991), Latif & Barnett (1995), Uvo et al. (1998), and Wang et al. (2004). Enfield & Mayer (1997) found a positive correlation (r = +0.5) between the positive phase of ENSO and NTA SSTA from lag = +4 to +5. Several authors, such as Alexander et al. (2002) and He et al. (2020), state that positive NTA SSTA immediately follow the mature phase of El Niño, about 3–5 months after the ENSO peaks, a result consistent with the findings of this study. Latif and Grötzner (2000) has found delayed response of the equatorial Atlantic to ENSO (Niño 3), with SST anomalies in the eastern equatorial Atlantic lagging those in the equatorial Pacific by six months. Concerning the STA SSTA, these SSTA may be related to strengthening the South Atlantic Subtropical Gyre, it means, in response to a local and not a remote forcing (Lübbecke et al., 2010).

Influence of the ENSO phases and intensities on the precipitation in Maranhão

Figures 4 to 11 show the total composites for the WEA SSTA and the precipitation in Maranhão for different phases (El Niño *vs* La Niña) and intensities (strong *vs* moderate). The total composites were computed to determine how WEA Ocean responds to Equatorial Pacific SSTA, regardless of the region where they occurred (if Niño 1+2, 3, 3.4, and/or 4). The total composites of WEA SSTA for El Niño years showed cold SST over the ocean throughout the months, with negative SSTA practically dominating the region (Figures 4 and 5). In strong events (Figure 4), the negative SSTA are even more intense in the equatorial region and the STA (around −0.6°C) from May to October (MJJASO), with the peak of negative SSTA occurring from May to August and even more consistently in the eastern band. Negative SSTA anomalies (around −0.4°C) are also found over the Continental Shelf of Maranhão (CS–MA), particularly from June to November (JASON). These anomalies are spreading towards the northwest from the Maranhão Gulf. The most intense negative SSTA arrive later (AMJ quarter) in the WEA during strong El Niño and are persistent over time until SON quarter (Figure 4). In moderate events (Figure 5) the largest negative SSTA (around −0.4°C) are observed in the NTA from February to June (FMAMJ), when they disperse towards the equatorial Atlantic band and then in the STA from July to October (JASO). In DJF and NDJ, the moderate El Niño signal is weak over the WEA SSTA. The SSTA in the WEA has a shorter duration (5 months) and happens earlier compared with the strong events (6 months). The impacts on the CS–MA SSTA are weak during moderate El Niño. Previous studies, including Araújo et al. (2013), have confirmed our results, showing negative SSTA in the WEA during El Niño events, in their case, from March to May.

Figures 6 and 7 show the total composites of precipitation anomalies in the state of Maranhão for strong and moderate El Niño events. Our findings show a strong relationship between El Niño and the precipitation in the Maranhão state. Composites of negative SSTA during strong El Niño events were associated with negative precipitation anomalies in Maranhão, except in DJF, when positive precipitation anomalies are spreading over the state with the largest values occurring in the central-northwest sector (Figure 6). The most significant response to these events occurred in the MAM, AMJ, MJJ, and NDJ quarterlies, which covers the months of the rainy season of Maranhão (March–April–May), with the central, northern, and eastern tip sectors of regions being more affected. However, the negative precipitation anomalies started to weaken from the JJA quarter and strengthen again in NDJ. This agrees with the results of Souza et al. (2000), who found negative precipitation anomalies over Maranhão associated with El Niño event, from March to May. For the moderate El Niño phase, in turn, positive and negative precipitation anomalies alternated, both with smaller associated intensity. Positive precipitation anomalies were observed from DJF to JJA, as well as negative precipitation anomalies from JAS to NDJ (Figure 7). In DJF, AMJ, and MJJ quarterlies. the most evident positive anomalies have appeared in Maranhão, which also include the two months (April and May) of its rainy season, with the highest anomalies over the central, northern, and eastern sectors of the state. In JJA, a weak positive precipitation anomaly is seen in a central part of the state. From JAS to OND, negative precipitation anomalies were present but relatively weaker. However, in NDJ, negative precipitation anomalies were strong in almost the entire state of Maranhão (Figure 7).

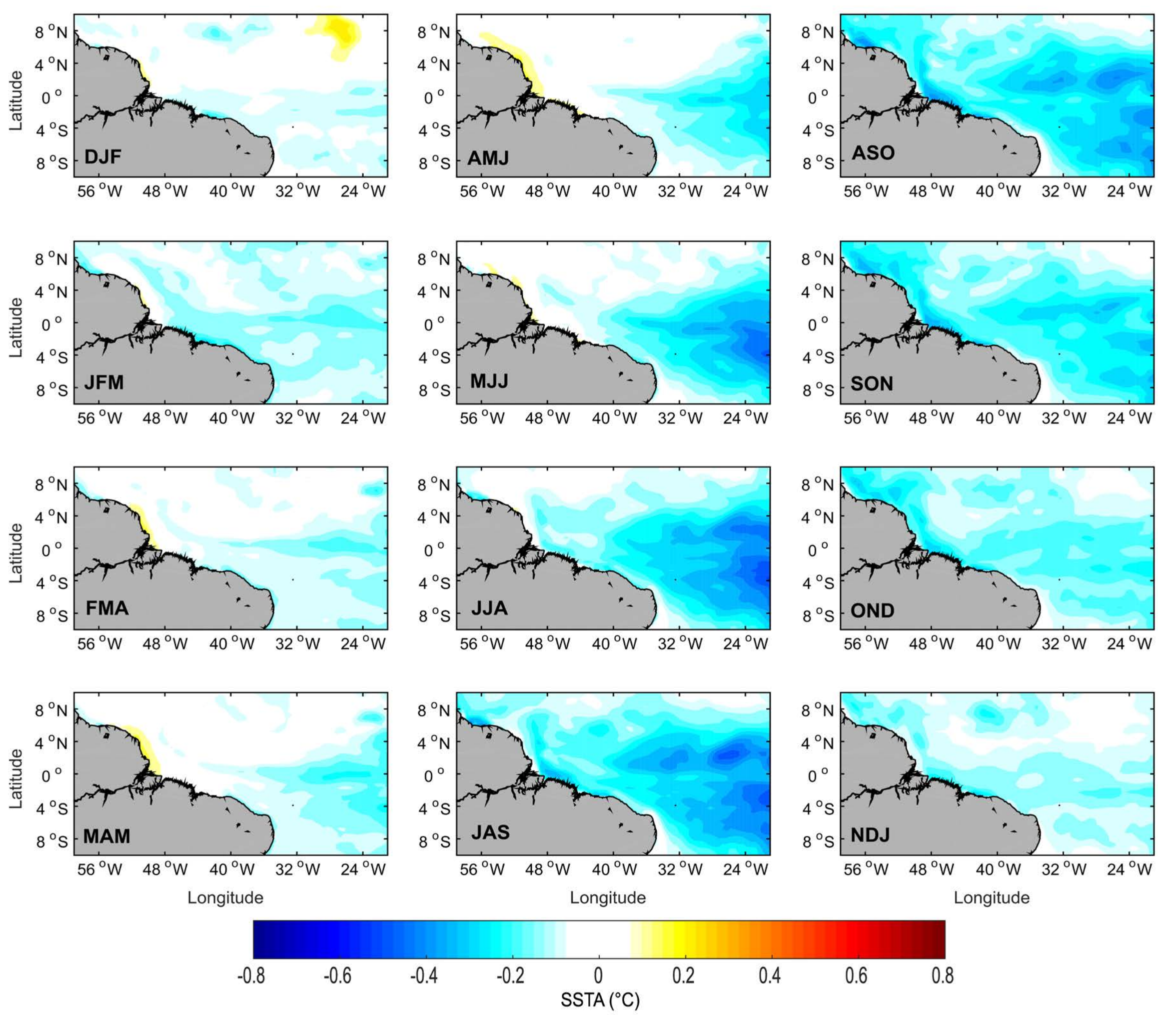

Figure 4. Total composites of quarterly SST anomalies in the Western Equatorial Atlantic (WEA) Ocean for strong El Niño events in the Equatorial Pacific region.

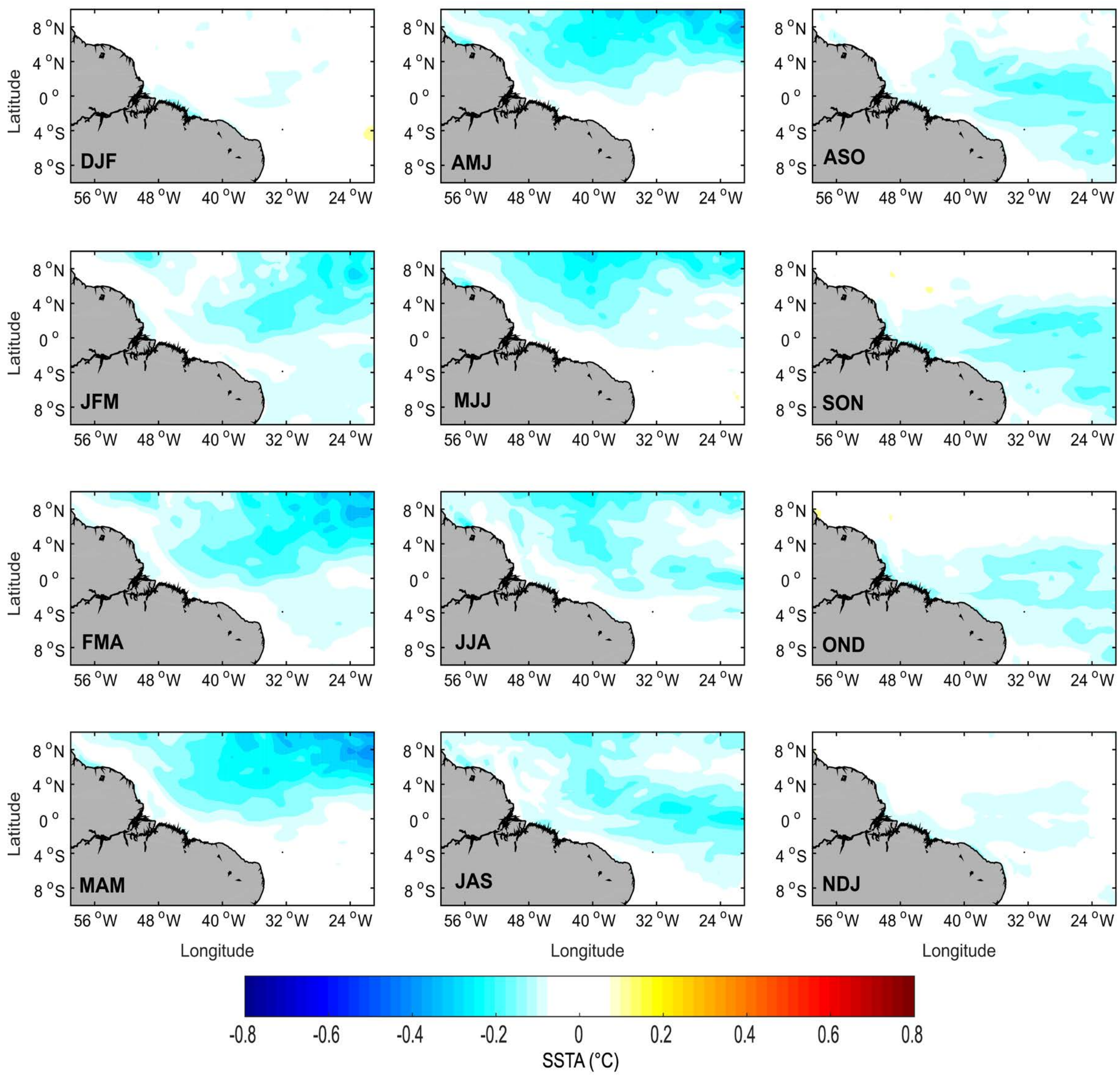

Figure 5. Total composites of quarterly SST anomalies in the Western Equatorial Atlantic (WEA) Ocean for moderate El Niño events in the Equatorial Pacific region.

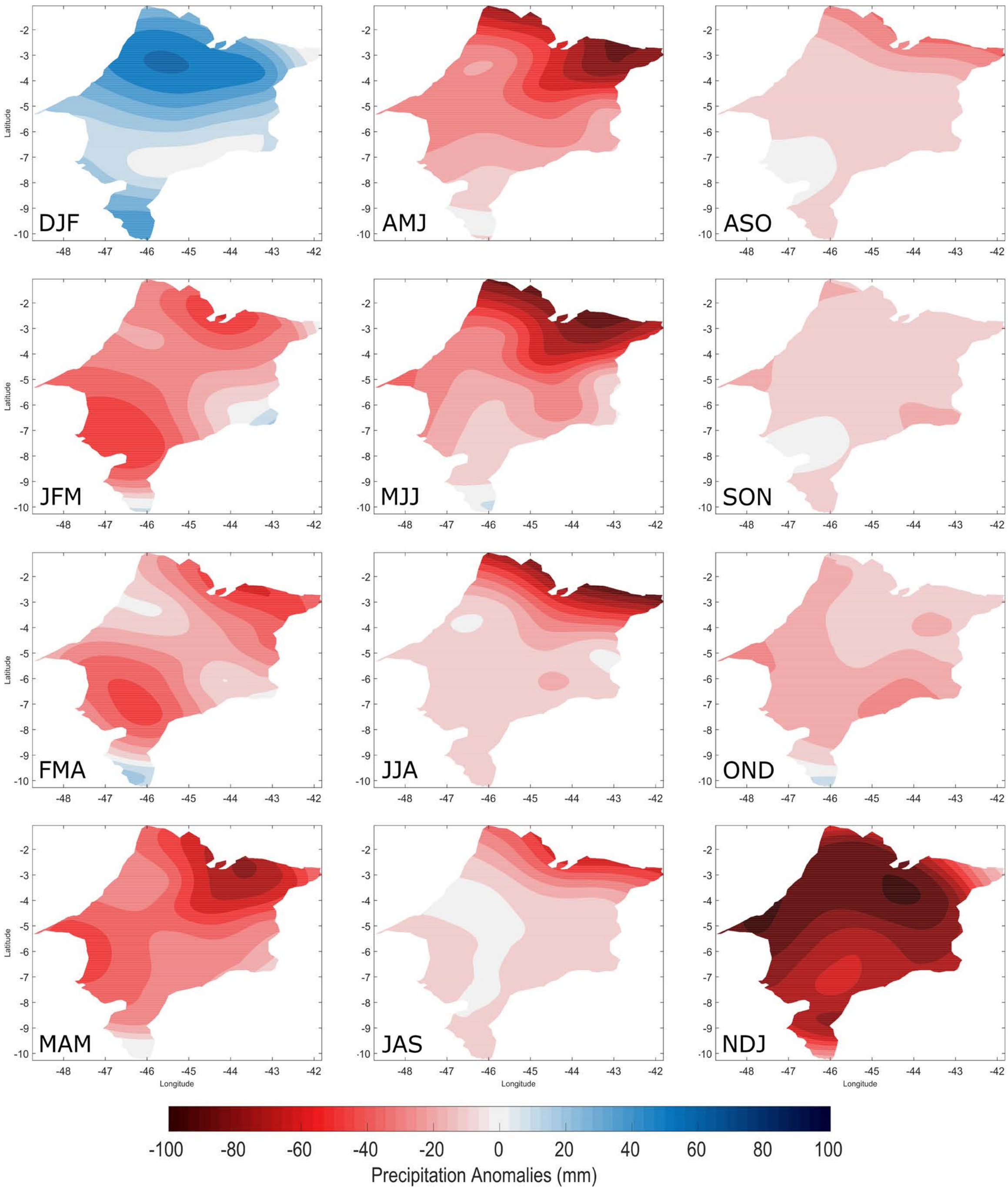

Figure 6. Total composites of quarterly precipitation anomalies in the state of Maranhão for strong El Niño events in the Equatorial Pacific region.

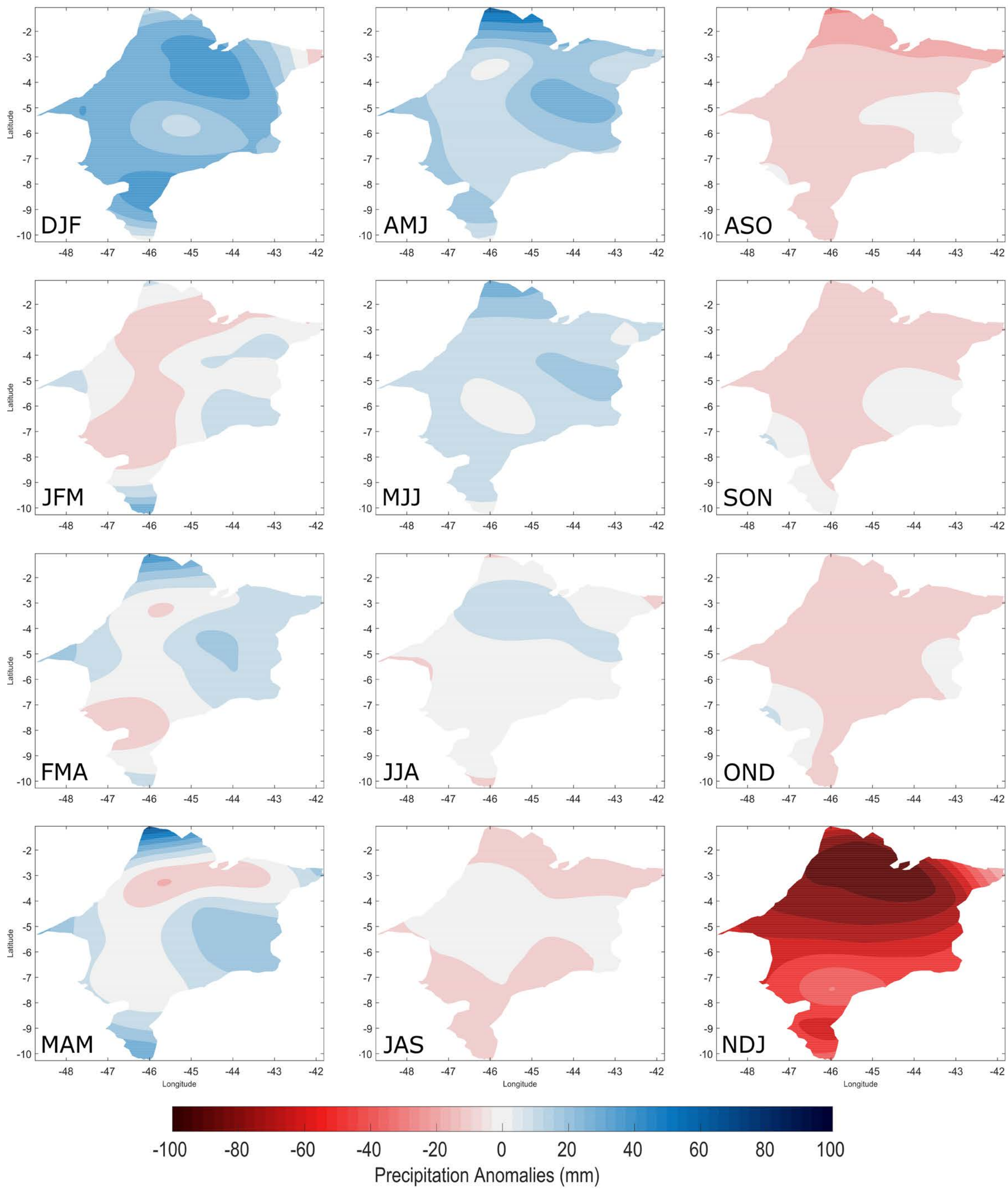

Figure 7. Total composites of quarterly precipitation anomalies in the state of Maranhão for moderate El Niño events in the Equatorial Pacific region.

The total composites of WEA for La Niña events show a predominance of positive SSTA, with a similar spatial pattern between strong (around +0.8°C) and moderate (around +0.3°C) events, with smaller intensity for the latter composites (Figures 8 and 9). For the strong events, positive SSTA are primarily configured over the STA from January to April (JFMA), moving further into the equatorial band from May to September (MJJAS) (Figure 8). The strongest positive anomalies are seen in the eastern band, intensifying in January, and reaching a peak from April to July (Figure 8). The positive anomalies start to weaken in the eastern sector during the ASO quarter and this may be due to these once strong positive anomalies moving towards the east equatorial Atlantic (EEA). In OND and NDJ, the weak positive anomalies may be the final stop of the strong positive anomalies that moved eastward from the WEA. According to the studies by Munnich and Neelin (2005), positive SST anomaly patterns were found in the WEA area associated with La Niña event in the Niño 3.4 in May, and this event induced wind stress anomalies in the WEA, which in turn, displaced warm water from the WEA towards the EEA. In moderate events, the positive SSTA are observed over the STA, especially from January to August (JFMAMJJA) (Figure 9). Positive SST anomalies in the WEA are weak during moderate La Niña events. At the DJF and NDJ, the La Niña signal in the WEA is practically nonexistent (Figure 9). These results align with those of Munnich & Neelin (2005) and Nicholson & Selato (2000), who found positive SSTA in the WEA during La Niña events, particularly from January to September, and tend to weaken from October to November.

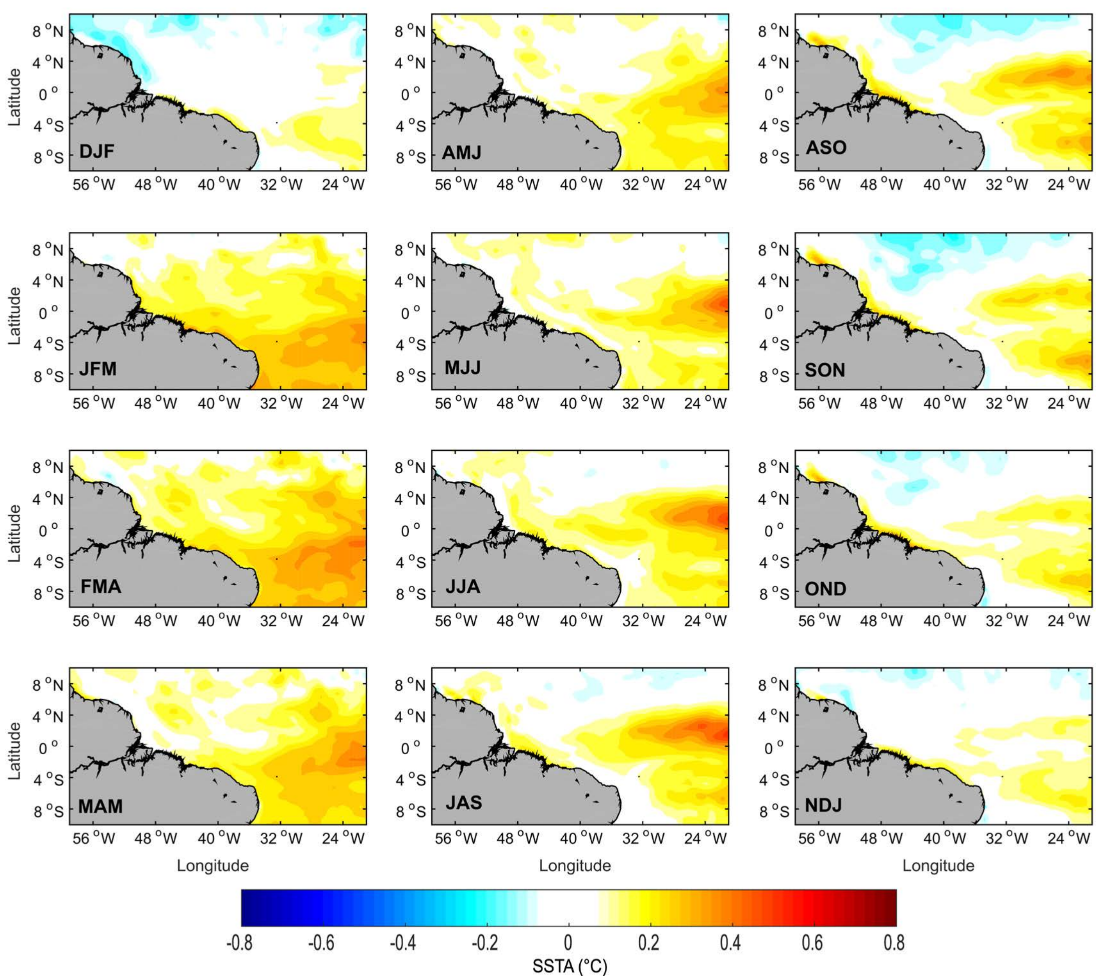

Figure 8. Total composites of quarterly SST anomalies in the Western Equatorial Atlantic (WEA) Ocean for strong La Niña events in the Equatorial Pacific region.

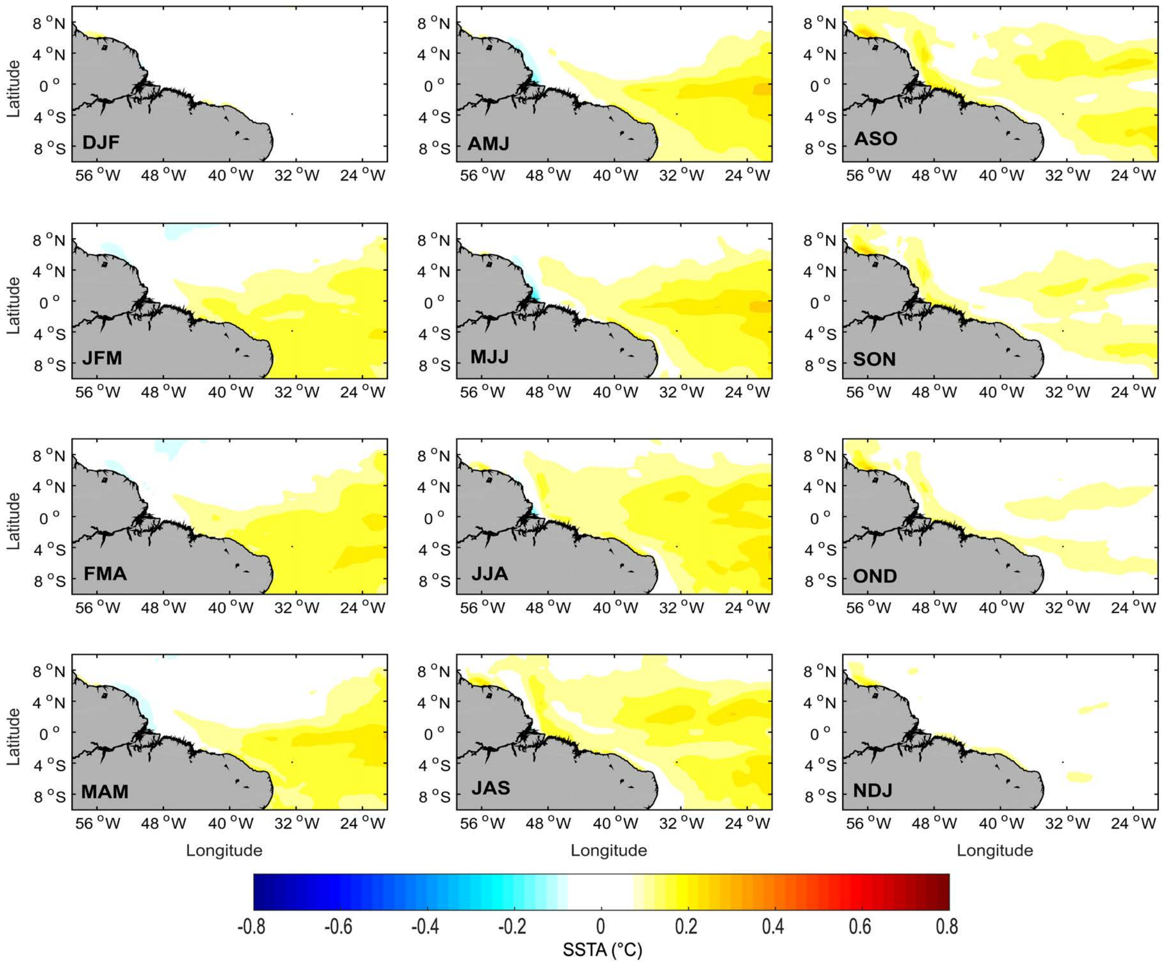

Figure 9. Total composites of quarterly SST anomalies in the Western Equatorial Atlantic (WEA) Ocean for moderate La Niña events in the Equatorial Pacific region.

Figures 10 and 11 show the total composites of precipitation anomalies in the state of Maranhão for strong and moderate La Niña events. The WEA SSTA under the influence of strong La Niña events has been associated with either positive or negative precipitation anomalies. The DJF quarter show the strongest positive precipitation anomaly. The positive precipitation anomalies in JFM and FMA are more widespread in the central and northern sectors of Maranhão. The rainy season (MAM, AMJ, and MJJ quarter) shows positive precipitation anomalies covering almost the entire state, with the most noticeable positive anomalies concentrated in the central, northern, and eastern sectors. At the JJA, JAS, and ASO quarterlies, the positive precipitation anomalies weaken and are more confined to the northern sector of Maranhão, as weak negative precipitation anomalies appear in a part of the central and southern sectors. The La Niña signal is weak in terms of precipitation during the SON and OND quarterlies. In contrast to the positive anomalies, negative anomalies are generally weak, except in NDJ, which shows an evident negative precipitation anomaly (Figure 10). Regarding the influence of moderate La Niña events, positive precipitation anomalies were well pronounced from DJF to JJA, with a peak in DJF, MAM, AMJ, and MJJ (Figure 11). The DJF quarter shows the most intense positive precipitation anomaly in the state. From JFM to MJJ, positive precipitation anomalies spread across most of the state, with the most noticeable anomalies concentrated in the central, northern, and eastern tip sectors, and especially during the rainy season (MAM). At the JJA, JAS, and ASO quarterlies, positive precipitation anomalies are observed in the northern sector, whereas weak negative precipitation anomalies appear in a part of the central sector. The moderate La Niña signal on precipitation is absent in the SON quarter and relatively weak in OND. The negative anomalies of precipitation are generally weak, except in NDJ, which shows an evident negative precipitation anomaly (Figure 11).

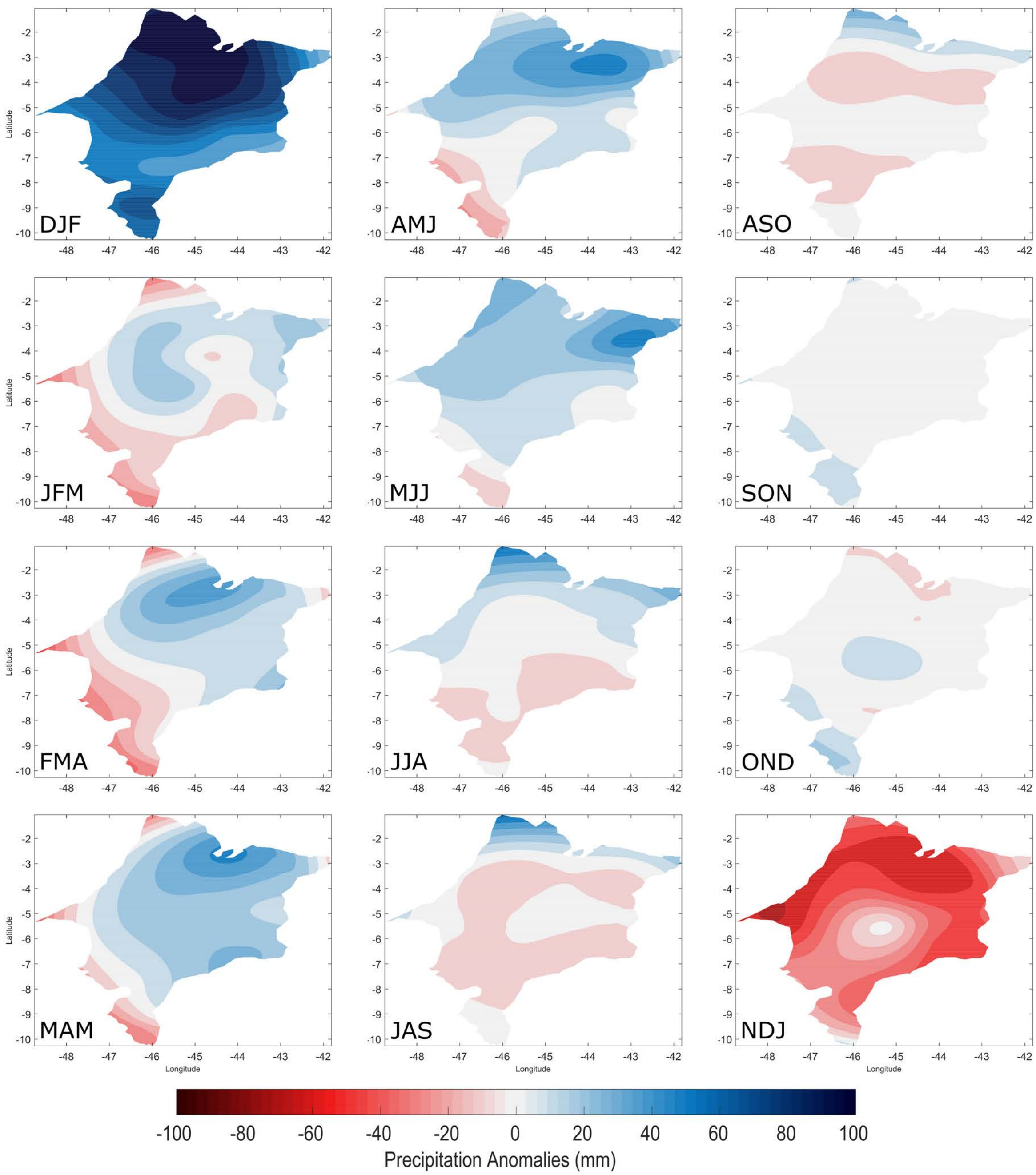

Figure 10. Total composites of quarterly precipitation anomalies in the state of Maranhão for strong La Niña events in the Equatorial Pacific region.

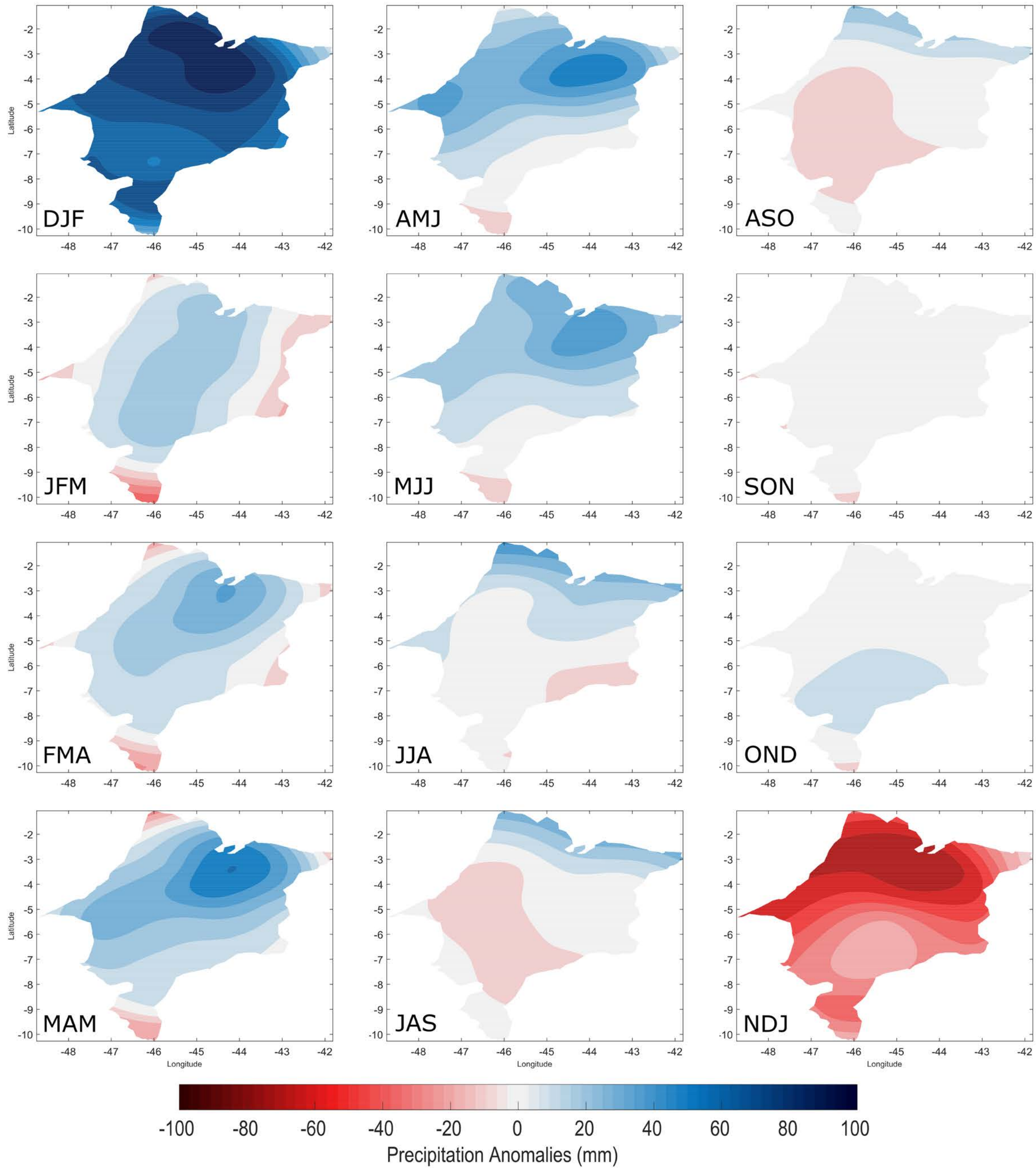

Figure 11. Total composites of quarterly precipitation anomalies in the state of Maranhão for moderate La Niña events in the Equatorial Pacific region.

In short, the impacts of ENSO events on precipitation in Maranhão are stronger in the central, northern, and eastern tip sectors of the state, and less in the southern sector. The WEA SSTA during El Niño (La Niña) events are related to negative (positive) precipitation anomalies in Maranhão, with the peak in MAM, AMJ, MJJ, JJA, and NDJ (DJF and AMJ), respectively. Strong El Niño events significantly impact the reduction of precipitation over the state, whereas moderate El Niño events have mild effects. Positive precipitation anomalies occur in Maranhão in its rainy season (MAM).

The results found in this study are consistent with those found by Nascimento et al. (2017) who showed that the northern region of Maranhão presented wet and drought events related to La Niña and El Niño, respectively. They also reported extremes of droughts in the southern region of the state. The studies from Grimm & Tedeschi (2009), Araújo et al. (2013), Tedeschi et al. (2016), and Cai et al. (2020) showed that the greatest impacts of El Niño and La Niña on the NEB precipitation occur in March and April, which result in reduced and increased precipitation, respectively. In addition to the influence of ENSO on precipitation in the NEB, the TA SSTA resulting from local variability modes have also modulated the precipitation in this region during its rainy season, such as the Atlantic Meridional Mode (e.g.; Rodrigues et al., 2011; Andreoli et al., 2016; Kayano et al., 2018; Soares, 2019) and the Atlantic Niño (Servain et al., 1982; Zebiak, 1993; Wu et al., 2004; Hounsou-Gbo et al., 2020). Tedeschi et al. (2016) and Soares (2019) report that the joint action of the Atlantic Meridional Mode and ENSO positive phases in the quarterly of March–April–May intensify the negative precipitation anomalies over the NEB region.

CONCLUSION

In this study, 36 years (from 1980 to 2015) of SST monthly data are used to investigate the influence of the different phases and intensities of ENSO events on the seasonal and interannual variability of the SST in the WEA Ocean. It also assesses the impacts of the WEA SSTA in ENSO events on the seasonal precipitation in the state of Maranhão.

Our results showed a weak linear correlation between the Niño regions and the WEA Ocean at lag = 0. Seasonally, the most pronounced SSTA found in the WEA region were related to strong El Niño and La Niña events. Based on the ONI, more moderate ENSO events occurred from 1980 to 2015 than strong ones. Among the events classified as both strong and moderate, La Niña events predominated, with the Niño 3.4 being the region with the largest number of events. Concerning the action of zonal (Pacific-Atlantic) teleconnections, a decrease and an increase in the WEA SST was observed in El Niño and La Niña years, respectively, with a delay of 3–5 quarterlies after the ENSO peaks.

Regarding the impact of the WEA SSTA during ENSO events on the precipitation in Maranhão, the results showed that the central, northern, and eastern sectors of the state are the most affected by this internal variability, as also appointed by Nascimento et al. (2017). The positive precipitation anomalies in these regions, especially in the quarter of DJF and MAM, AMJ, MJJ, were associated with the WEA SSTA resulting from the La Niña events, with the negative ones happening in the MAM, AMJ, MJJ and NDJ quarterlies and resulting from El Niño. Strong El Niño events influence a greater precipitation deficit in Maranhão than the moderate events. Positive precipitation anomalies in Maranhão are more closely related to moderate than to strong La Niña events.

This study is pioneer in investigating the influence of different Niño regions, phases, and intensities of ENSO on SST variability in the WEA region, analyzing the impacts of zonal (Pacific-Atlantic) teleconnections on the seasonal variability of precipitation in Maranhão. With the findings of this study, we concluded that ENSO significantly influences the SST variability in the WEA region, and adds to the action of the Atlantic Meridional Mode (Soares, 2019) on determining the quality of the rainy season (MAM) over the state. This joint action is being analyzed to be included in future publications.

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AUTHOR CONTRIBUTIONS

L.A.M.S.: Formal analysis ; Investigation ; Validation; Writing – original draft.

C.K.P: Conceptualization; Funding acquisition; Investigation; Project administration; Supervision; Writing – original draft.

C.B.C.: Conceptualization Writing – review & editing.

L.G.L.: Funding acquisition; Resources Writing – review & editing.

A.M.B.M.: Formal analysis; Investigation.

T.M.S.F.: Formal analysis.

H.N.B. and H.L.S.S.: Writing – review & editing.

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