



Non-ENSO Fluctuations of Sea Surface Temperature variability in the Far Northeastern tropical Pacific

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ABSTRACT

An analysis of sea surface temperature anomalies (SSTA) in the far northeastern tropical Pacific (0°–10°N, 80°W–100°W), off the coast of Central America, using reanalysis data for the period 1982–2018 and applying linear correlation techniques, reveals anomalous warming episodes not associated with El Niño events within the equatorial band (5°S–5°N). The 2014 event confirms that these warmings produce climatic impacts comparable to those generated by El Niño, although their differentiation remains challenging. The identified episodes exhibit characteristics like the *Coastal El Niño* observed off Peru. To distinguish them, the classifications *Coastal Inca El Niño* and *Coastal Maya El Niño* are proposed, according to their geographic domain of occurrence. It is hypothesized that these warmings may originate from extratropical processes and could be linked to fluctuations in the North Pacific Gyre. These findings open a new line of research into regional ocean–atmosphere phenomena and contribute to advancing the understanding of processes that strengthen climate diagnostics and prediction in the region.

Palabras clave: Pacífico tropical nororiental extremo; ENOS; El Niño costero.

Fluctuaciones de la temperatura superficial del mar del Pacífico tropical nororiental extremo no asociadas a ENSO

RESUMEN

Mediante el análisis de anomalías de temperatura superficial del mar (SSTA) en el extremo nororiental del Pacífico tropical (0°–10°N, 80°W–100°W), frente a las costas de Centroamérica, utilizando datos de reanálisis para el período 1982–2018 y aplicando técnicas de correlación lineal, se evidencian episodios de calentamiento anómalo no asociados al fenómeno El Niño en la franja ecuatorial (5°S–5°N). El evento de 2014 confirma que estos calentamientos generan efectos climáticos similares a los producidos por El Niño, sin embargo se dificulta su diferenciación. Los eventos identificados presentan características comparables al denominado El Niño costero observado frente a Perú. Para distinguirlos, se propone la clasificación El Niño costero-inca y El Niño costero-maya, debido al ámbito geográfico de ocurrencia. Se plantea la hipótesis de que estos calentamientos podrían tener un origen extratropical y estar vinculados a fluctuaciones en el Giro del Pacífico Norte. Estos hallazgos abren una nueva línea de investigación sobre fenómenos océano-atmosféricos regionales y contribuyen a mejorar la comprensión de los procesos que fortalecen el diagnóstico y la predicción climática en región.

Keywords: Far Northeastern tropical Pacific; ENSO; coastal El Niño.

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1. Introduction

The extreme phases of interannual variability in sea surface temperature (SST) in the tropical Pacific—manifested in the El Niño (EN) and La Niña (LN) phenomena (Trenberth, K., 1997), alterations in atmospheric pressure (Southern Oscillation—SO), and changes in the general circulation of the tropical atmosphere—induce significant climate anomalies (such as air temperature and precipitation) in various regions of the world, particularly in tropical America (Haylock et al., 2005; Lyon & Barnston, 2005; Marengo et al., 2018; Li et al., 2011; Espinoza et al., 2009; Alfaro, 2002; Córdoba-Machado et al., 2014; Pabón & Montealegre, 2017; Salas et al., 2020; Cai et al., 2020), where they may lead to disasters. One pathway toward reducing disaster risk associated with these extreme phases is the development of climate prediction and early warning systems (Hildebrand, 2014; Vaughan & Dessai, 2014; Adams et al., 2015), grounded in an improved understanding of the climate variability linked to EN-LN-SO (hereafter ENSO). This highlights the critical need to advance our understanding of the physical processes operating in the tropical Pacific.

In the countries of tropical America, operational climate prediction still largely relies on the established relationship between ENSO and regional climate, despite recent years seeing the emergence of new knowledge regarding other processes that influence regional climate (Saenz et al., 2022). Monitoring of the ocean-atmosphere system in the tropical Pacific, as well as climate prediction schemes, continues to be framed by the conceptual model of the canonical El Niño developed during the 1970s and 1980s (Rasmusson & Carpenter, 1982). As a result, most of the indices used for monitoring and prediction focus on SST behavior in the central sector of the equatorial Pacific (Niño 3 and Niño 3.4 regions, between 5°S and 5°N), primarily through the Oceanic Niño Index (ONI) calculated from observations in the Niño 3.4 region, although the Niño 1+2 region is also monitored. However, research from the past two decades, along with regional forecasting experience, suggests that it is not only the central-eastern tropical Pacific that causes climate anomalies in tropical America; the eastern tropical Pacific also generates a significant signal in regional climate, which requires more detailed analysis.

In the spatial distribution of SST anomalies (SSTA) in the tropical Pacific, various configurations have been identified (Trenberth & Smith, 2006; Ashok et al., 2007; Kug et al., 2009; Takahashi et al., 2011; Johnson, 2013; Capotondi et al., 2015; Capotondi et al., 2020; Di Lorenzo et al., 2022), with some studies pointing to the existence of up to nine distinct ENSO-like patterns (Johnson, 2013). According to Capotondi et al. (2015), ENSO diversity can be recognized through differences in the spatial distribution of SST anomalies, the amplitude of these fluctuations, the onset processes, and their overall life cycle. For example, phases such as El Niño Modoki, the Canonical El Niño, the Eastern Pacific El Niño, and the Central Pacific El Niño can be identified, among others. Similarly, Capotondi et al. (2020) improved the characterization of ENSO diversity across different categories to identify the leading dynamical processes, precursors, and impacts. The resulting climate effects—primarily expressed through anomalies in air temperature and precipitation—and their impacts, which often result in disaster situations, vary according to the type of EN or LN event.

From the diversity of expressions identified in the 5°S–5°N equatorial belt (Johnson, 2013), the El Niño (EN) and La Niña (LN) situations classified as canonical and Modoki have received the most attention (Takahashi, 2011; Marathe et al., 2015). Likewise, analyses of the climatic effects of the tropical Pacific in different parts of the world have focused on differentiating the impacts of each EN or LN type, including in tropical America (Li et al., 2011; Córdoba-Machado et al., 2014). However, in the past two decades, other anomalous situations distinct from canonical and Modoki EN or LN events have been identified and studied, such as the coastal El Niño (Takahashi et al., 2014; Peng et al., 2024), a form of EN concentrated in the southeastern tropical Pacific, confined off the Peruvian coast. This variant is associated with pronounced climatic anomalies in the region and has been responsible for severe impacts, including disasters in multiple tropical American nations (Takahashi et al., 2018). Based on this finding, Peru has incorporated the Coastal El Niño Index (ICEN) into its regional climate monitoring and forecasting. ICEN is calculated as the three-month running mean of monthly SST anomalies in the Niño 1+2 region (Takahashi et al., 2011; ENFEN Committee, 2012; Takahashi et al., 2014; Woodman & Takahashi, 2014), and it has a strong influence on the country's climatology. Similarly, efforts have been made to develop indices other than the

ONI to better represent regional processes off the coasts of Ecuador (Bravo de Guenni et al., 2016) and Colombia (Rodríguez-Rubio, 2013).

Research on interannual variability in the eastern tropical Pacific has primarily focused on the southeastern sector (Niño 1+2 region, off the coasts of Ecuador and Peru) (Dewitte & Takahashi, 2017; Hu et al., 2019), while adjacent areas off Colombia and Central America have received little attention regarding the specific features of SST variability and their impact on regional climate. In the comprehensive review by Amador et al. (2016), interannual variability in the northeastern tropical Pacific is largely attributed to traditional ENSO behavior, with no particularities highlighted for the region. The authors also note that few studies have addressed this part of the Pacific. Nevertheless, earlier descriptions include those by Herrera-Cervantes & Parés-Sierra (1994) on low-frequency SST variations off the California coast; Kessler (2006) on ocean circulation near Central America; Amador et al. (2006) and Fiedler & Lavín (2017) on atmospheric forcing in the eastern tropical Pacific; and Wang & Fiedler (2006), who describe a “warm pool” north of the equator.

Oceanographic features in the northeastern tropical Pacific include the Northeastern Tropical Pacific Warm Pool (NTPWP), a vast area off the southern coasts of Mexico and Guatemala with SSTs exceeding 28.5°C (Wang & Enfield, 2001); the Costa Rica Dome, characterized by a shallow thermocline; and the Tehuantepec Bowl, where the thermocline is relatively deep (Kessler, 2006). Maloney et al. (2008) and Maloney & Kiehl (2002) analyzed intraseasonal SST variability in the NTPWP and found that it influences local precipitation. Wang & Fiedler (2006) studied interannual variability in the NTPWP and associated it with ENSO, without identifying fluctuations driven by other processes. Similarly, Karnauskas & Busalacchi (2009a) compared interannual SST variability in the NTPWP with that of the central tropical Pacific (Niño 3 region) between 1982 and 2006, finding a correlation of 0.9, which led them to conclude that ENSO controls interannual variability in this region. They further explored its effect on Central American precipitation, found that the mature phase of the El Niño event can cause a rapid enhancement of the eastern Pacific intertropical convergence zone, which directly leads to a positive rainfall anomaly over Central America (Karnauskas & Busalacchi, 2009b). Misra et al. (2002) also concluded that interannual variability in the NTPWP is strongly linked to ENSO. Maloney & Kiehl (2002) and Maloney et al. (2008) found that intraseasonal SST variability in the region affects local convection and precipitation patterns.

Interannual SST variability in the northeastern tropical Pacific also regulates the variability of tropical cyclones in the region (Jin et al., 2014; Martínez-Sánchez & Cavazos, 2014; Zhao & Raga, 2015; Ji et al., 2024). However, most studies attribute this variability entirely to ENSO, overlooking other potential drivers. Dong & Zhou (2014), for instance, suggest that interdecadal processes in both the Pacific and Atlantic may influence SST variability in the study region. Short-term field campaigns (Raymond et al., 2004; Yepes et al., 2019; Sentić et al., 2022) have provided insights into mesoscale variability and air-sea coupling in the eastern tropical Pacific, with the objective of improving their parameterization and representation in coupled modeling frameworks. These efforts contribute to our understanding of broader processes such as interannual variability, which is the focus of this study. The observation campaign by Yepes et al. (2019), conducted in the least-studied part of the northeastern tropical Pacific (Colombian maritime waters), aimed to improve knowledge of regional circulation and the processes that drive the heavy rainfall observed in this sector (Mejía et al., 2021), and it is expected to shed further light on ocean-atmosphere processes in this region of the planet.

Based on SST behavior in the northeastern tropical Pacific during the second half of 2014, Pabón-Caicedo & Martínez (2016) and Moreno-Rincón & Pabón-Caicedo (2018) proposed that very particular situations might occasionally occur in this sector, somewhat different from those already defined or associated with ENSO. One example is the warming event in 2014 (Hu & Fedorov, 2017; Hu et al., 2018), which preceded the strong 2015–2016 EN event and may have been connected to anomalous SST behavior in the California Current System, as described by Zaba & Rudnik (2016), Hartmann (2015), McClatchie et al. (2016) and Benthuysen et al. (2020). Moreno & Pabón (2018) note that similar events may have occurred in 1990, 2000, the second half of 2006, and the second half of 2008, when mild warming (with positive anomalies near 0.5°C) in parts of the study area preceded the EN events of 1991–1992 (strong), 2002–2003 (moderate), 2007 (weak), and 2009–2010 (strong), respectively.

Song et al. (2012), analyzing environmental conditions for sardine spawning in the California Current System (30°–38°N), found that SST variability in the region is associated not only with ENSO-related fluctuations but also with slightly different conditions, such as those observed during the transition from the 1999–2001 LN to the 2002–2003 EN, and from the 2005–2006 LN to the 2006–2007 EN. Another research, de Alba - Guzman (2024), over a decade, evaluated the spatiotemporal variation in the benthic structure and composition of an insular coral community in the Northeastern Tropical Pacific, finding increase in abundance of coral communities for the 2010 - 2011 la Niña event, in contrast, with 2015 - 2016 El Niño event decrease in different coral community coverage.

In summary, there is evidence of regional-scale SST warming events in the northeastern tropical Pacific that differ from conventional EN or LN episodes (Dewitte & Takahashi, 2017; Takahashi et al., 2018; Hu et al., 2018). However, most studies have focused on the southern sector (south of the equator) of the eastern tropical Pacific. Even in the most recent analysis (Hu et al. 2018; Peng et al. 2024) on differences between macro-scale ENSO events (across the tropical Pacific) and regional (coastal) events, the focus remains on the Niño 1+2 zone, corresponding to the southern portion of the so-called Far Eastern Tropical Pacific. The area north of the equator — the far northeastern tropical Pacific, off the coasts of Colombia, Panama, Costa Rica, Nicaragua, El Salvador, Honduras, and Guatemala — remains unexplored. This highlights the need to examine interannual SST variability in the northeastern tropical Pacific to identify potential situations that differ from canonical and Modoki EN and LN events and to determine how frequently such events may occur.

2. Materials and methods

The area of the eastern tropical Pacific analyzed in this study spans from the equator to 10°N and from 80°W to 100°W (Figure 1). This region is approximately located between the Galápagos Islands (Ecuador), Cocos Island (Costa Rica), and the coastlines of Costa Rica, Panama, and Colombia, south of the Gulf of Papagayo (Costa Rica). Figure 1 also shows a broader area extending from the equator to 10°N and from 95.5°W to 107.5°W. It is important to note that this sector of the northeastern tropical Pacific exhibits a gap in regular ocean-atmospheric measurement points, which are mostly limited to islands and the coast, sporadic cruises, and satellite sensor data. Even in the proposed expansion of ocean observations for the tropical Pacific (Smith et al., 2019), this area continues to lack permanent or regular measurement systems.

For this reason, the present analysis relies on monthly SSTA data obtained from the NOAA IO.v2 reanalysis (from <http://www.cdc.noaa.gov/>) (Reynolds et al., 2007; Huang et al., 2021), with a spatial resolution of 1° x 1° (approximately 110 x 110 kilometers). The time series, covering the period from January 1982 to August 2018, were extracted for the points labeled A through H shown in Figure 1. To identify behaviors distinct from ENSO, these SSTA time series were compared with the Oceanic Niño Index (ONI) for the same period (<https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml#history>).

To compare interannual behavior in the northeastern tropical Pacific with that of the central Pacific (represented by the ONI), the SSTA time series for points A–H were smoothed using a five-month moving average, creating a new set of SSTA-MM5 series.

The variability of precipitation in Central America and northern South America was analyzed using monthly precipitation anomaly (PA) time series obtained from NOAA NCEP CPC CAMS_OPI v0208. These data covered the same period (January 1982 – August 2018) and have a spatial resolution of 2.5° x 2.5°, equivalent to 220 x 220 kilometers. Because the objective is to visualize regional rather than site-specific precipitation variability, neither station data nor high-resolution datasets were used. The resolution of the NOAA NCEP CPC CAMS_OPI v0208 dataset is considered adequate for this purpose. Each PA time series represents the behavior of precipitation within the corresponding grid cell.

Initially, a zero-lag linear correlation analysis was conducted between the SSTA time series for selected points in the northeastern tropical Pacific (see Figure 1) and the ONI. This aimed to determine whether the behavior of these points matched or resembled the ONI; low correlation coefficients would suggest a distinct pattern in the northeastern Pacific and the possibility of identifying regional events different from those detected using the ONI. Correlation coefficients were also calculated between the ONI and the SSTA time series for points A–H using time lags of 0, 1, 2, 3, 4, and 5 months in the SSTA series. This approach seeks to identify any delayed signal transmission from the central Pacific to the study area, allowing for a distinction between regional and large-scale phenomena.

Correlation analysis was also used to examine the connection between SSTA at the labeled points (Figure 1) and monthly precipitation anomalies (PA) in Central America and northern South America. Specifically, correlation coefficients were calculated between each SSTA time series (points A–H) and the PA time series from 29 grid points across the study region (marked with black dots in Figure 1), using time lags of 0 to 5 months for the PA relative to the SSTA.

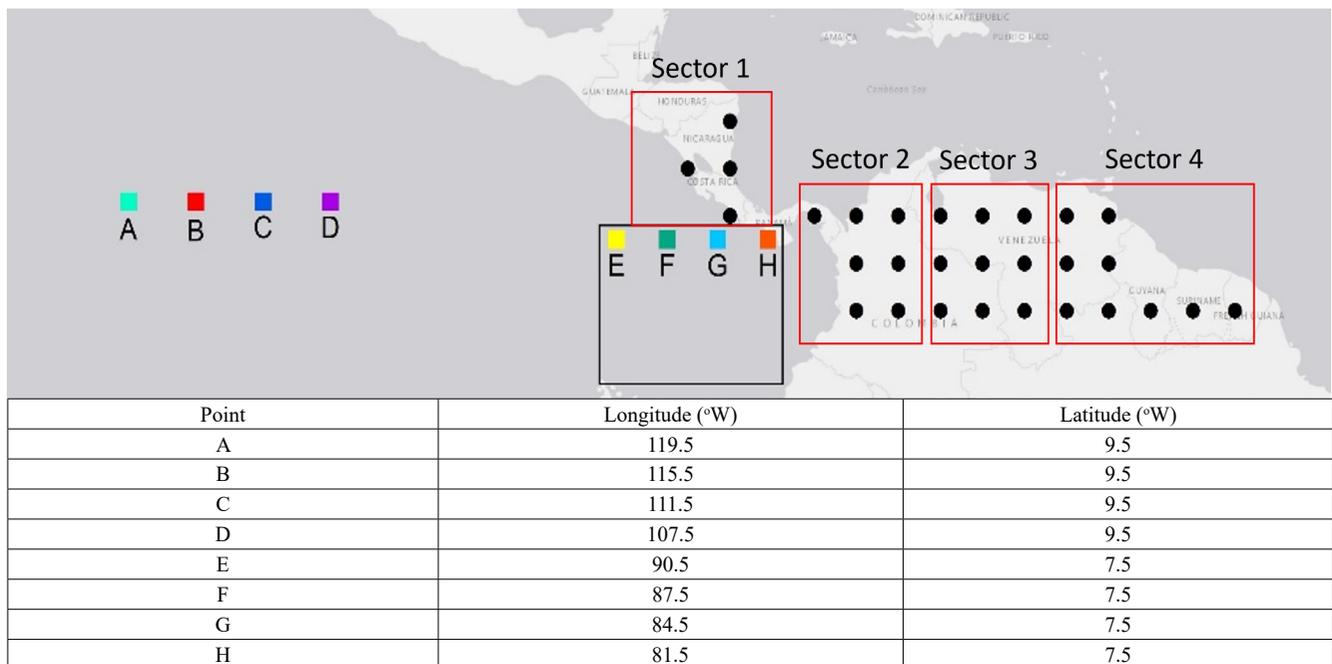


Figure 1. Study area. The inner box highlights the northeastern equatorial Pacific sector. Colored squares labeled with capital letters (coordinates provided in the table to the right) indicate the locations of NOAA IO.v2 grid points used to extract the SSTA time series. Black dots represent the locations of the NOAA NCEP CPC CAMS_OPI v0208 grid points from which monthly precipitation time series were extracted. Red-lined boxes indicate the following sectors: Sector 1 – Central America; Sector 2 – Colombia; Sector 3 – Venezuela; Sector 4 – Northeastern South America.

3. Results

Figure 2 shows the comparison between the ONI series and the SSTA-MM5 series at points A, B, C, D, E, F, G, and H (as indicated in Figure 1) during the 2013–2018 period. It can be observed that the behavior at points E, F, G, and H in 2014 differs from the pattern indicated by the ONI, suggesting that the warming in this area was not associated with the El Niño (EN) event, which began to be detected in the ONI in the last quarter of 2014. A warming wave is observed between late 2013 and early 2014 at points G and H; a warming close to 1°C was recorded throughout 2014 at point E, while at point F it remained between 0.5°C and 1°C. The warming with SSTA values above 0.5°C lasted for approximately 11 months, starting between December 2013 and December 2014.

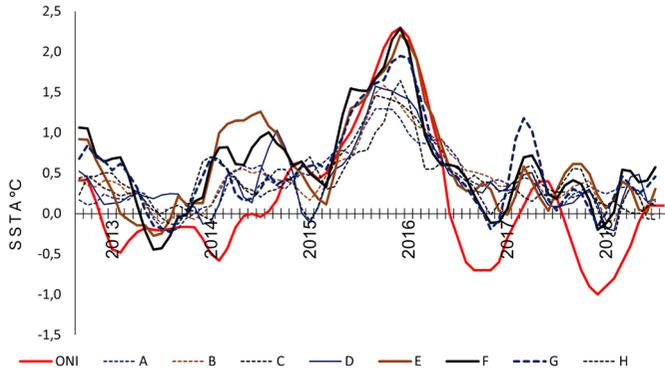


Figure 2. Comparison between the ONI series and the SSTA-MM5 series at points A, B, C, D, E, F, G, and H (as shown in Figure 1).

The correlation between the SSTA-MM5 series and the ONI (Figure 3) reveals a greater dispersion in the graphs corresponding to points E, F, G, and even H. However, correlation coefficients are significantly lower only at points D and H. The dispersion observed in the graphs of Figure 3, as well as the slightly lower correlation values at the indicated points, confirm the earlier observation from Figure 2: there is a distinct difference SSTA variability in a sector of the northeastern tropical Pacific compared to that of the central tropical Pacific represented by the ONI.

Figure 4 presents the spatial distribution of the correlation coefficients calculated between the SSTA series at each grid point of the NOAA IO.v2 reanalysis and the ONI series, as well as the SSTA series in the Niño 3 and Niño 1+2 regions, with lags of 0, 1, 2, 3, 4, and 5 months. A distinct area of low correlation coefficients (around 0.5) is observed north of points A, B, C, D, E, F, G, and H, while higher values (above 0.8) are concentrated further south in the equatorial channel. It is also notable that for correlations with ONI and Niño 3 at all lags in time, there is a sector near the Galápagos Islands (between 85°W and 95°W) in the equatorial channel where the correlation coefficient drops to around 0.5. This area of low correlation values expands as the lag increases. In contrast, in the correlation with Niño 1+2, this low-correlation area in the equatorial channel does not appear; however, it is evident that the correlation coefficient decreases along this strip as the lag increases.

In Figure 5, which summarizes the relationship between SSTA at points A, B, C, D, E, F, G, and H and precipitation anomalies recorded at various locations in Central America and northern South America, although the obtained correlation coefficients are relatively low (ranging from -0.3 to 0.1), negative correlation values predominate. This indicates an inverse response of regional precipitation variability to variability in the northeastern tropical Pacific. It is also evident that this inverse relationship is more pronounced for points A, B, C, D, and F, and affects both northern South America and Central America. The SST variability at points E, G, and H primarily influences precipitation in northern South America and, to a lesser extent, in Central America.

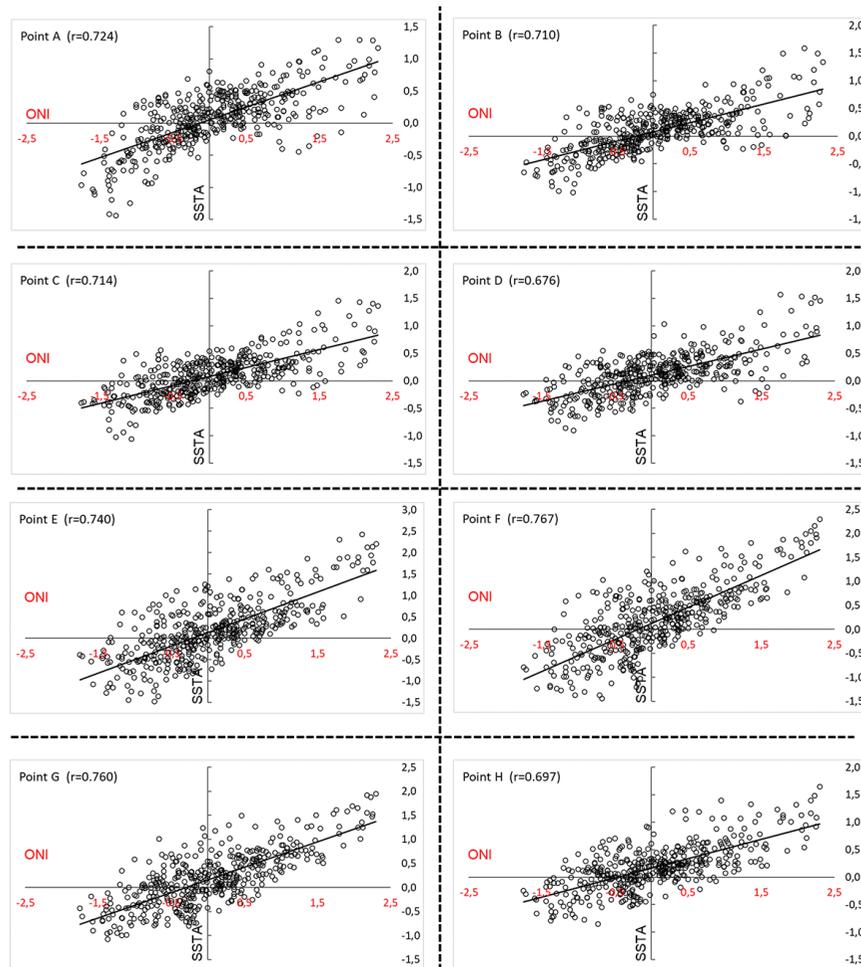


Figure 3. Relationship between the ONI series and the SSTA-MM5 series at points A, B, C, D, E, F, G, and H from Figure 1. The correlation coefficient (r) is indicated in each graph at the top left.

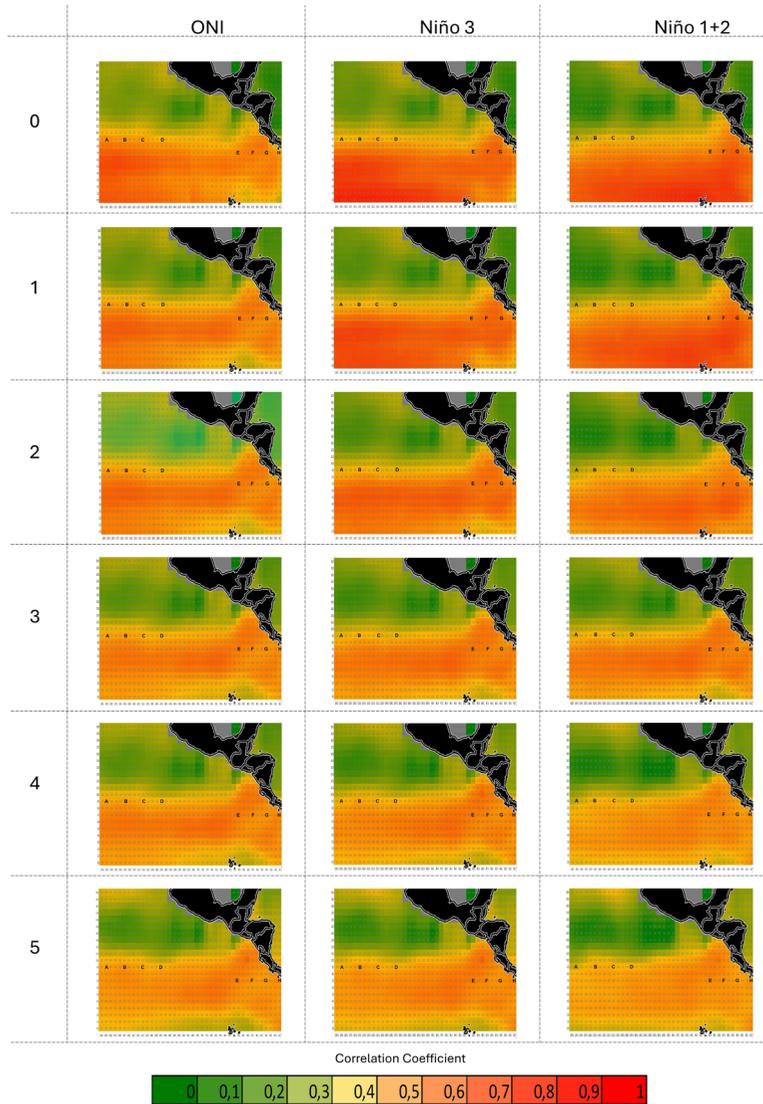


Figure 4. Correlation between the ONI series (left), Niño 3 region (center), and Niño 1+2 region (right) and the SST anomaly series at each grid point in the study area (120.5°W – 81.5°W and 0.5°N – 20.5°N). Correlations are calculated with 0-, 1-, 2-, 3-, 4-, and 5-month lags (as indicated by the numbers on the left) of the grid point series.

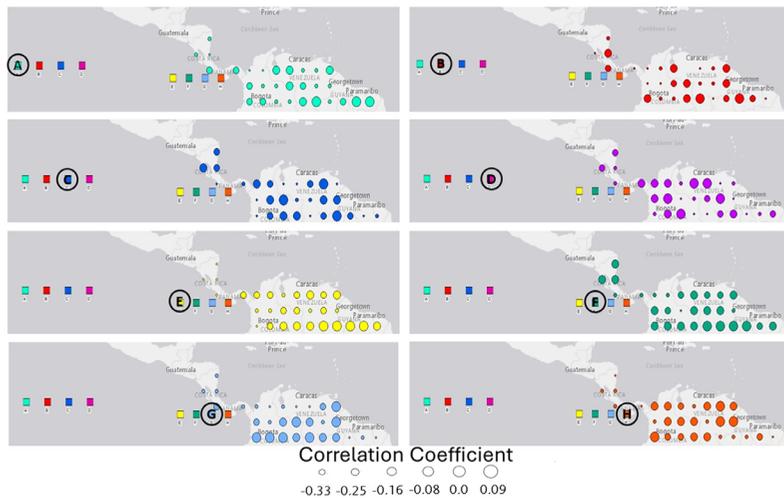


Figure 5. Linear correlation between the SSTA series of points located in Central America and northern South America. The correlation is calculated without time lag. In all cases, the values are negative, indicating an inverse correlation (The color of the dots over the continent corresponds to the color of the respective SSTA point; larger dots represent correlations closer to zero, while smaller dots indicate stronger negative correlations).

In Figure 6, the effect of SSTA recorded at points in the northeastern tropical Pacific on precipitation anomalies across four continental sectors is shown. Precipitation in sectors 1 (Central America) and 2 (Panama–Colombia) responds inversely to SSTA from all points. The 2014 warming event caused marked negative precipitation anomalies across the entire region encompassed by sector 1 (Central America). In sectors 3 (Venezuela) and 4 (Guyana, Suriname, French Guiana, and northern Brazil), the inverse relationship between precipitation anomalies and SSTA persists, although the anomalies are smaller than in sectors 1 and 2. Figure 6 also illustrates that the magnitude of negative anomalies decreases progressively eastward across the sectors.

Figure 7 shows the correlation coefficients between the SSTA series at different points and the precipitation anomaly (PA) series recorded at various stations within the designated sectors. In sector 1, low negative correlation coefficients were obtained between points A, B, C, and D and the precipitation anomalies. The correlations for points E and F were very low but positive, while highly positive correlations were observed for points G and H, indicating a clear response. Precipitation in sector 2 shows a greater sensitivity to SST

variability at the points analyzed: negative correlation coefficients are markedly low for points A and B, and especially for points C, D, and E. Point F exhibited a very weak inverse correlation, and points G and H showed weak positive correlations. In sector 3, the inverse correlation between PA and SSTA at points A through E was low, with a relatively stronger signal at point D. For points F, G, and H, the correlation was positive, especially marked for the latter two. In sector 4, correlations were quite strong—negative for points A, B, C, D, and F, and positive for points G and H—. In general terms, SST variability at the more westerly points correlated negatively with precipitation in all sectors, whereas points G and H elicited a positive response.

The precipitation deficit described in Figures 6 and 7, and in the corresponding text, is also confirmed by analyses from Amador et al. (2015) and Martínez et al. (2015a) regarding the climatic conditions in the region during 2014. Additionally, the severe drought experienced in the area is supported by reports from OCHA (2014), Flores-Mora and the World Bank (2014), as well as by coverage in various mass media outlets (print, radio, and television), particularly during the second half of 2014¹.

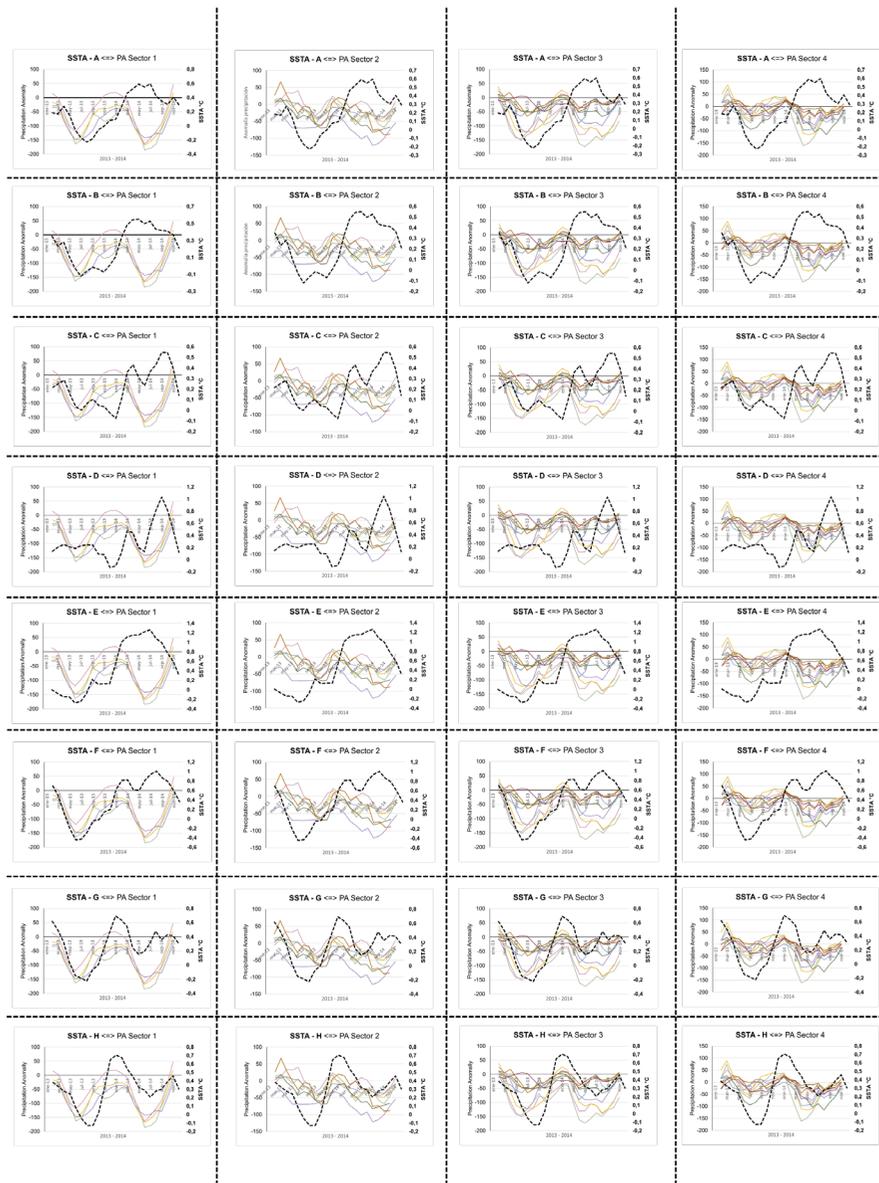


Figure 6. SSTA series from points A, B, C, D, E, F, G, and H (rows) compared with the precipitation anomaly series of stations located in sectors 1, 2, 3, and 4 (columns from left to right).

¹ The newspapers (dailies, weeklies, and monthly magazines), as well as radio and TV news programs in the countries of Central America and northern South America, reported the problems caused by the drought that developed over the region in the second half of 2014.

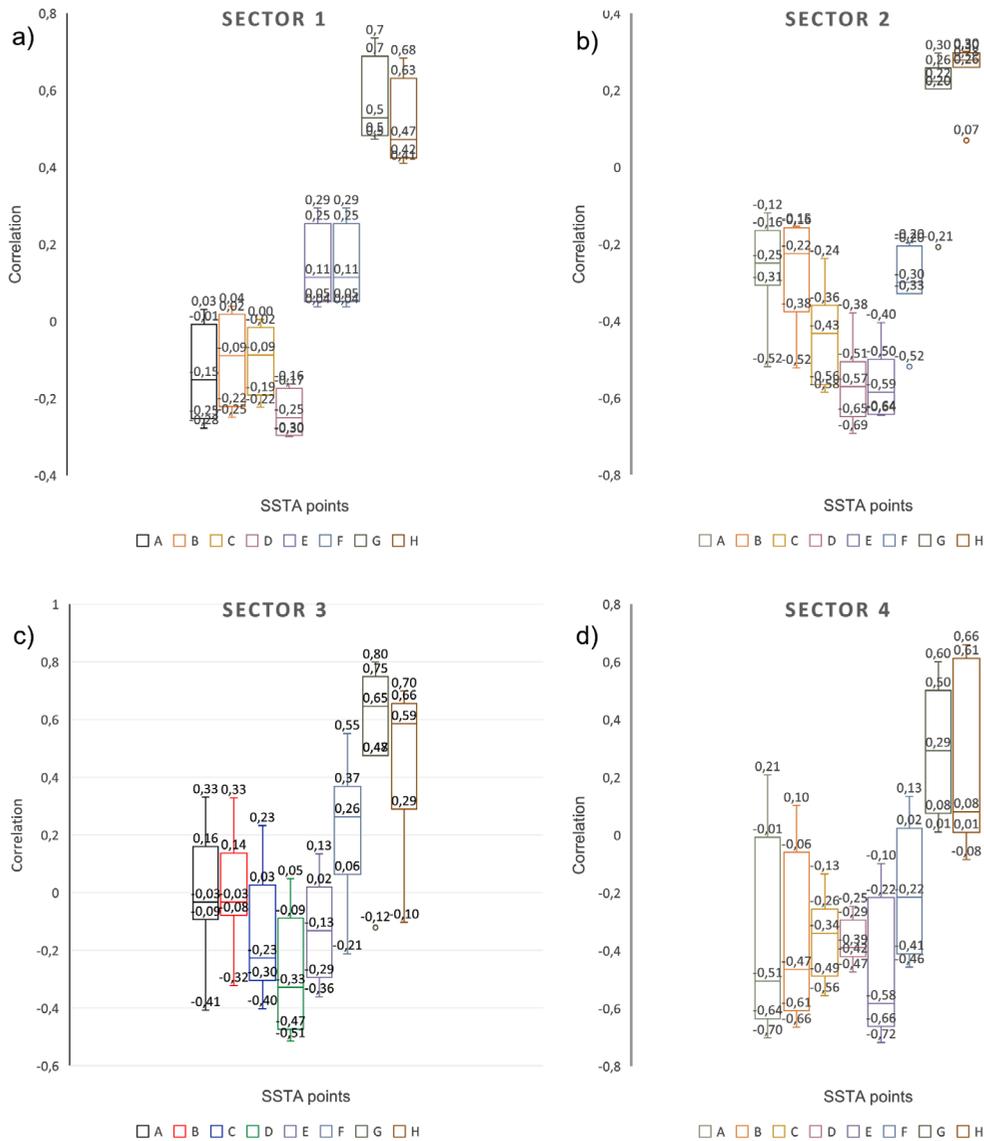


Figure 7. Comparative analysis of the correlations between the SSTA series from points A, B, C, D, E, F, G, and H and the precipitation anomaly series during the 2013–2014 period in sectors 1 (a), 2 (b), 3 (c), and 4 (d), as shown in Figure 1.

4. Analysis And Discussion

The results presented show that a sea surface warming event occurred in the northeastern tropical Pacific in 2014, which was not associated with the El Niño (EN) event that developed in 2015–2016. Nonetheless, the climatic impact in Central America and northern South America —characterized by precipitation deficits and drought— was like that typically produced by EN events. Therefore, it is not accurate to consider a single event spanning from 2014 to 2016, as suggested by several authors (e.g., Martínez et al., 2015a, b; Hu & Federov, 2017), climate monitoring and prediction centers (such as the International Research Center on El Niño – CIIFEN), and national meteorological and hydrological services in the region. In NOAA’s February 2015 *Climate Diagnostics Bulletin*, it was stated: “Taken together, these oceanic and atmospheric anomalies are consistent with borderline El Niño conditions” (NOAA, 2015a). From the March 2015 bulletin onward (NOAA, 2015b), and until September 2015, NOAA openly referred to a weak El Niño event; starting in October, it declared the presence of a strong, mature event, thus recognizing a continuous development from 2014. In the scientific literature, references to

a 2014–2016 event persist, often overlooking the distinct ocean-atmosphere processes that took place in the northeastern tropical Pacific during that period.

This analysis aligns with the findings of L’Heureux et al. (2015), who, based on ONI behavior between 2013 and 2014, described the prevailing ocean-atmosphere dynamics and concluded that El Niño conditions were not present during that time. Levine and McPhaden (2015) noted that during the boreal summer of 2014, Bjerknes feedback was not triggered due to an easterly wind burst, stating that the widely anticipated 2014–2015 El Niño event “did not materialize and did not even qualify as an El Niño under conventional definitions”. Interestingly, in the warm water volume series presented by Levine and McPhaden (2015), warming episodes like those in spring 2014 were also recorded in 1990 and 2001 —years that preceded El Niño events—. Furthermore, wind behavior analysis shows that easterly wind strengthening events occurred in both spring 1990 and spring 2014.

Tang et al. (2022) compared the 1997–1998 El Niño event with the 2015–2016 event, highlighting the latter’s distinctive development in the far northeastern tropical Pacific. They note that, in contrast to the strong SSTA observed in that region during 1997–1998, the anomalies during 2015–2016

were modest - even though the 2015–2016 El Niño was very intense in the central Pacific -. Clearly, the warming recorded off the coast of Central America in 2014 was not associated with the 2015–2016 El Niño event. However, according to Zhong et al. (2019), this warming may have played a key role in shaping the characteristics of the 2015–2016 event (e.g., the westward displacement of the core of maximum SST anomalies and its intensity).

To explore the origin of the 2014 warming event, Figure 8 presents monthly SSTA in the Pacific from October 2013 to December 2015. Notably, during the last quarter of 2013, an abnormally warm core is observed migrating eastward from the northwestern Pacific (off the coast of Japan) toward the eastern Pacific, eventually settling off the west coast of North America. This core was associated with the marine heatwave recorded in the North Pacific between 2013 and 2015 (Hartman, 2015; Di Lorenzo and Mantua, 2016; Chen et al., 2016). By January 2014, warming is evident off the coast of the California Peninsula—a phenomenon analyzed by McClatchie et al. (2016), who distinguished it from the subsequent effects of the 2015–2016 El Niño—. Between February and March 2014, the area of positive SST anomalies spread southward along the coasts of Mexico and Central America, forming a broad band of positive anomalies extending from the U.S. coast to Panama. A warm core also developed near 90°W (close to the Galápagos Islands, Ecuador) within the equatorial zone. Di Lorenzo et al. (2016) highlighted the emergence of an ENSO-like configuration during boreal autumn 2014 and the formation of a positive Pacific Decadal Oscillation (PDO) arc between January and May 2015. Analysis of the PDO series (<https://www.ncei.noaa.gov/access/monitoring/pdo/>) reveals a shift from negative to positive phase during boreal spring–summer 2014. Figure 8 also shows that the first equatorial Kelvin wave conducive to the 2015–2016 El Niño event emerged between May and June 2015 in the equatorial channel (5°S to 5°N).

The preceding description provides evidence that the origin of the 2014 warming event in the far northeastern Pacific, off the coast of Central America, was not associated with processes in the equatorial channel. Rather, it was generated by extratropical processes in the North Pacific, which can be traced from the North American coast and the California Current System (CCS), located slightly north of the study area of this work. The interannual variability of SST in this region may be associated with CCS variability, as can be inferred from the analysis presented above. Some authors (Amador et al., 2006; Karnauskas, 2009a, b) have identified ENSO as the main driver of variability in the northeastern tropical Pacific. However, recent investigations (Moreno-Rincón & Pabón-Cañedo, 2018), together with the analysis presented in this study, open the possibility that other modes—beyond ENSO—may influence interannual variability in the far northeastern tropical Pacific. One such mode is the CCS itself, where both warm and cold events can occur regardless of the presence of the positive or negative phases of ENSO (Fiedler & Mantua, 2017). Over the past four decades, warming events in the CCS without the presence of a positive ENSO phase were recorded in 1981, 1990, 1996, 2001, and the most intense one in 2013–2015. The years 2000, 2006, and 2008, previously noted by Moreno & Pabón (2018) as having exhibited warming events off the Central American coast, coincide with peaks in the CCS SST anomaly series presented by Fiedler & Mantua (2017).

Hartman (2015) analyzed the peculiar spatial distribution of SST anomalies observed in the North Pacific in 2014 by exploring three SST variability modes: the PDO, ENSO, and the North Pacific Oscillation (NPO) mode. Spatially, the latter two reproduce distributions similar to those observed in 2014. Hartman (2015) noted that the first mode, associated with the PDO and ENSO, explains 30% of the variance, while the second and third account for 8%. He argued that the second and third modes may be influenced by the North Pacific Gyre Oscillation (NPGO) (Di Lorenzo et al., 2008), also referred to as

the Victoria Mode (VM) (Li et al., 2023; Shi et al., 2023). Several authors have suggested that this latter mode may play a role in the development of El Niño conditions. In addition, Heidemann et al. (2024) identified a link between the Interdecadal Pacific Oscillation (IPO) and ENSO.

The presence of warming in the far northeastern tropical Pacific, such as that documented in 2014 and supported by the analysis in this study, suggests the possibility that coastal El Niño-type events may occasionally occur off the coast of Central America, like those observed south of the equator, off the coast of Peru. These events—here referred to as “*Maya Coastal El Niño*”—to distinguish them from the Peruvian events, which could be called “*Inca Coastal El Niño*”—contribute to the variability of climate phenomena in the tropical Pacific. Such events produce extreme precipitation deficits in Central America and northern South America, often leading to drought-related disasters. This opens a potential line of research to further explore the frequency, dynamics, and drivers of these events; their relationship with the PDO, NPGO, VM, and ENSO; their coastal propagation southward toward Central America; and their impacts on the climate of Central America, the Caribbean, and northern South America.

Conclusions

This study demonstrated that warming events with sea surface temperature anomalies (SSTA) near or above 0.5°C occur in the far northeastern tropical Pacific, with durations ranging from 6 to 12 months. These events are not reflected in the SSTA series of the Niño 1+2, Niño 3, or Niño 3.4 regions, nor in the ONI index, and resemble the coastal warming events observed off the coast of Peru, south of the equator, commonly referred to as *Coastal El Niño* events. For differentiation, we propose to refer to the Central American counterpart as “*Maya Coastal El Niño*” (with the southern events referred to as “*Inca Coastal El Niño*”).

Based on the 2014 warming event, it was established that *Maya Coastal El Niño* events result in reduced precipitation in Central America and northern South America, leading to drought conditions that negatively affect the socioeconomic systems of countries in the region.

The investigation into the possible origin of these warming events in the far northeastern tropical Pacific determined that they are of extratropical origin and likely associated with fluctuations in the North Pacific Gyre that occasionally extend further south, beyond the California Current System. This finding opens a new line of research into the dynamics of *Maya Coastal El Niño* events and invites further exploration into the role of the South Pacific Gyre in the evolution of *Inca Coastal El Niño* events.

The results of this study also underscore the importance of monitoring ocean–atmosphere processes in this sector and incorporating such analysis into climate diagnostics and prediction efforts. This calls for the strengthening of observational systems in the far northeastern tropical Pacific.

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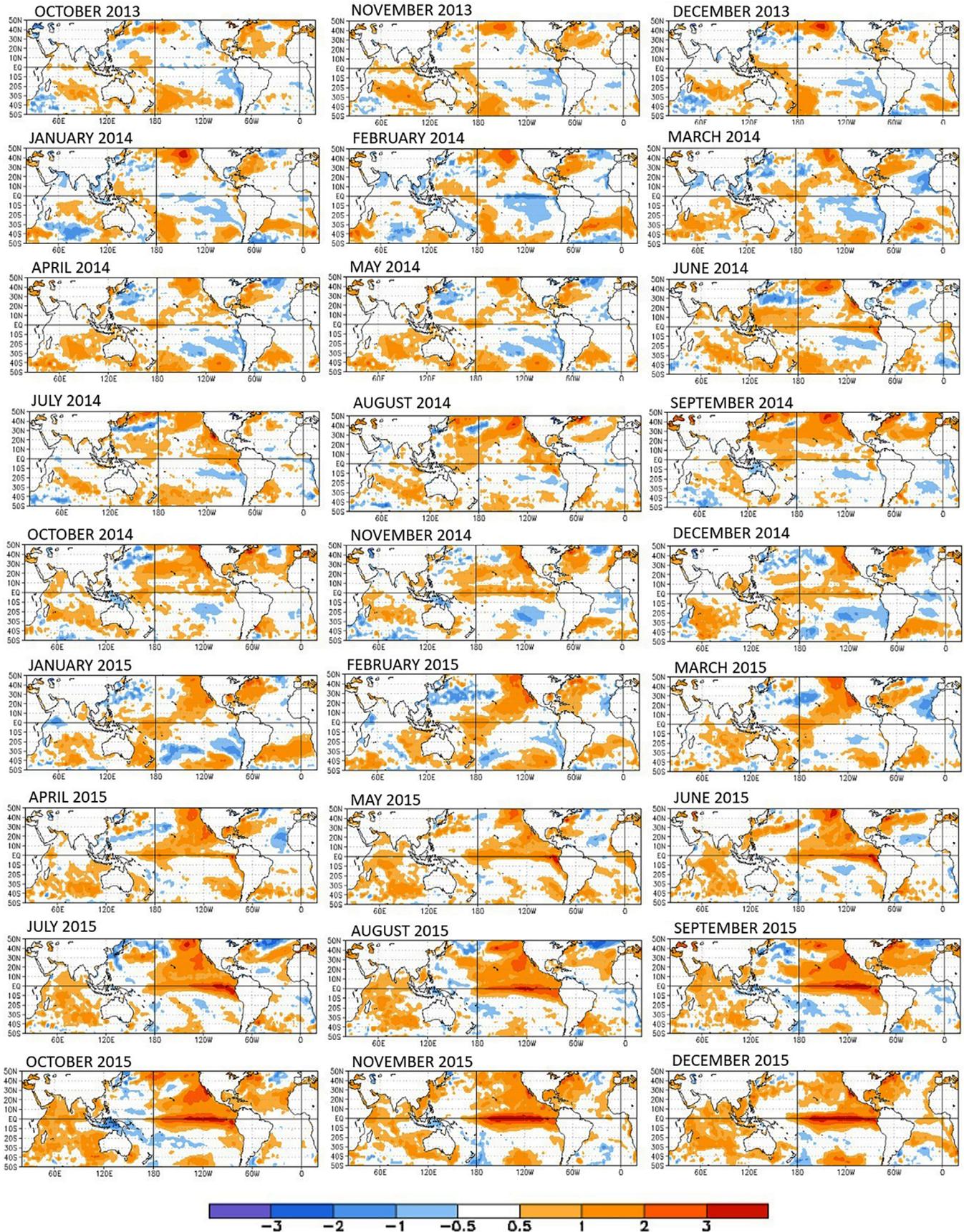


Figure 8. Monthly sea surface temperature anomalies from October 2013 to December 2015. Constructed using images published in the NOAA *Climate Diagnostics Bulletin* during the specified period, accessed via the following link: https://www.epc.ncep.noaa.gov/products/CDB/CDB_Archive_html/CDB_archive.shtml

References

- Adams, P., Hewitson, B., Vuaghan, C., Wilby, R., Zebiak, S., Eitland, E. (2015). Call for an ethical framework for climate services. *WMO Bulletin*, 64(2), 51-54.
- Alfaro, E. (2002) Some characteristics of the precipitation annual cycle in Central America and their Relationships with its Surrounding Tropical Oceans. *Tópicos Meteorológicos y Oceanográficos*, 7, 99-115.
- Amador, J. A., Alfaro, E. J., Lizano, O. G., Magaña, V. O. (2006). Atmospheric forcing of the Eastern Tropical Pacific: A review. *Progress in Oceanography*, 69, 101-142.
- Amador, J. A., Hidalgo, H. G., Alfaro, E. J., Duran-Quezada, A.M., Calderón, B., Vega, C. (2015). Central America. [in "State of the Climate in 2014"]. *Bull. Amer. Meteor. Soc.*, 96(7), S174-S176.
- Amador, J.A., Rivera, E.R., Duran-Quesada, A.M., Mora, G., Sáenz, F., Calderón, B., Mora, N. (2016). The easternmost tropical Pacific. Part I: A climate review. *Rev. Biol. Trop. (Intern. J. Trop Biol)*, 64 (S), S1-S22.
- Ashok, K., Behera, S., Rao, S., Weng, H. & Yamagata, T. (2007). El Niño Modoki and its possible teleconnection. *Journal of Geophysical Research*, 1-27.
- Benthuyens, J. A., Oliver, E. C. J., Chen, K., & Wernberg, T. (2020). Editorial: Advances in understanding marine heatwaves and their impacts. *Frontiers in Marine Science*, 7, 147. <https://doi.org/10.3389/fmars.2020.00147>
- Bravo de Guenni, L., García, M., Muñoz, A., Santos, J., Cedeño, A., Perugachi, C. & Castillo, J. (2016). Predicting monthly precipitation along coastal Ecuador: ENSO and transfer function models. *Theoretical and Applied Climatology*. 129(3), 1059-1073.
- Cai, W., McPhaden, M. J., Grimm, A. M., Rodrigues, R. R., Taschetto, A. S., Garreaud, R. D., Dewitte, B., Poveda, G., Ham, Y-G., Santoso, A., Ng, B., Anderson, W., Wang, G., Geng, T., Jo, H-S., Marengo, J.A., Alves, L. M., Osman, M., Li, S., Wu, L., Karamperidou, C., Takahashi, K. & Vera, C. (2020). Climate impacts of the El Niño – Southern Oscillation on South America. *Nature Reviews Earth & Environment*, 1, 215-231. DOI: 10.1038/ s43017-020-0040-3
- Capotondi, A., Wittenberg, A., Newman, M., Di Lorenzo, E., Yu, J., Braconnot, P., . . . Yen, S. (2015). Understanding Enso Diversity. *Bulletin American Meteorological Society*, 921-938.
- Capotondi, A. (2020). ENSO diversity. In M. J. McPhaden, A. Santoso, & W. Cai (Eds.), *El Niño Southern Oscillation in a Changing Climate* (pp. 65–86). *American Geophysical Union/Wiley*. <https://doi.org/10.1002/9781119548164.ch4>
- Chen, S., Wu, R., Chen, W., Yu, B., & Cao, X. (2016). Genesis of westerly wind bursts over the equatorial western Pacific during the onset of the strong 2015–2016 El Niño. *Atmospheric Science Letters*, 17(7), 384-391.
- Comité ENFEN. (2012). Definición operacional de los eventos El Niño y La Niña y sus magnitudes en la costa de Perú. Comité Técnico del Estudio Nacional del Fenómeno El Niño (ENFEN), Lima, Perú.
- Córdoba-Machado, S., Palomino-Lemus, R., Gámiz-Fortis, S., Castro-Díez, Y. & Esteban-Parra, M. (2014). Assessing the impact of El Niño Modoki on seasonal precipitation in Colombia. *Global and Planetary Change*, 41-61.
- de Alba-Guzmán, C.; Cabral-Tena, R.A.; Rodríguez- Zaragoza, F.A.; Tortolero-Langarica, J.d.J.A.; Cupul-Magana, A.L.; Rodríguez-Troncoso, A.P. (2024) Decadal Changes in Benthic Community Structure and Function in a Coral Community in the Northeastern Tropical Pacific. *Diversity*, 16, 372. <https://doi.org/10.3390/d16070372>
- Dewitte, B., Vazquez-Cuervo, J., Goubanova, K., Illig, S., Takahashi, K., Cambon, G., . . . Ortlieb, L. (2012). Change in El Niño flavours over 1958–2008: Implications for the long-term trend of the upwelling off Peru. *Deep-Sea Research II*, 143-156.
- Dewitte, B. & Takahashi, K. (2017). Diversity of moderate El Niño events evolution: role of air–sea interactions in the eastern tropical Pacific. *Climate Dynamics*. DOI:10.1007/s00382-017-4051-9
- Di Lorenzo E., Schneider N., Cobb K. M., Chhak, K., Franks P. J. S., Miller A. J., McWilliams J. C., Bograd S. J., Arango H., Curchister E., Powell T. M. and P. Rivere, (2008): North Pacific Gyre Oscillation links ocean climate and ecosystem change. *Geophys. Res. Lett.*, 35, L08607, doi:10.1029/2007GL032838.
- Di Lorenzo, E., & Mantua, N. (2016). Multi-year persistence of the 2014/15 North Pacific marine heatwave. *Nature Climate Change*, 6(11), 1042-1047.
- Di Lorenzo E., Xu T., Zhao Y., Newman M., A. Capotondi A., Stevenson S., Amaya D.J., Anderson B.T., Ding R., Furtado J.C., Joh Y., Liguori G., Lou J., Miller A.J., Navarra G., Schneider N., Vimont D.J., Wu S., and H. Zhang. (2022) Modes and Mechanisms of Pacific Decadal-Scale Variability. *Annual Review of Marine Science*. <https://doi.org/10.1146/annurev-marine-040422-084555>
- Dong, L. & Zhou, T. (2014). The formation of the recent cooling in the eastern tropical Pacific Ocean and the associated climate impacts: A competition of global warming, IPO, and AMO. *Journal of Geophysical Research: Atmospheres*, 119(19), 11-272.
- Espinoza, J., Roanchail, J., Guyot, J., Cochonnau, G., Naziano, F., Lavado, W., De Oliveira, E., Pombosa, R. & Vauchel, P. (2009). Spatio Temporal rainfall variability in the Amazon basin countries (Brazil, Perú, Bolivia, Colombia and Ecuador. *International Journal of Climatology*, 29, 1574-1594 DOI: 10.1002/joc.1791
- Fiedler P. C., Lavín M. F. (2017). Oceanographic Conditions of the Eastern Tropical Pacific. In: Glynn P., Manzello D. and Enochs I. (editors) *Coral Reefs of the Eastern Tropical Pacific. Coral Reefs of the World*, 8. https://doi.org/10.1007/978-94-017-7499-4_3
- Fiedler, P. C., Mantua, N. J. (2017). How are warm and cool years in the California Current related to ENSO? *J. Geophys. Res. Oceans*, 122, 5936-5951, DOI:10.1002/2017JC013094
- Flóres-Mora, C. y Banco Mundial. (2014). Sequía histórica: cuatro países, 40 días sin lluvia, 2 millones con hambre en Centroamérica. Sección "Noticias". <https://www.bancomundial.org/es/news/feature/2014/09/10/sequias-centroamerica>
- Hartmann, D. L. (2015). Pacific Sea surface temperature and the winter of 2014. *Geophys. Res. Lett.*, 42, 1894–1902. DOI: 10.1002/2015GL063083.
- Haylock, M., Peterson, T., Alves, L., Ambrizzi, T., Anunciação, Y., Baez, J., . . . Vincent, L. (2005). Trends in Total and Extreme South American Rainfall in 1960-2000 and Links with Sea Surface Temperature. *American Meteorological Society*, 1490-1512.
- Heidemann, H., Cowan, T., Power, S. B. et al. (2024). Statistical relationships between the Interdecadal Pacific Oscillation and El Niño – Southern Oscillation. *Clim Dyn*, 62, 2499-2515. <https://doi.org/10.1007/s00382-023-07035-8>
- Herrera-Cervantes, H., Parés-Sierra, A. (1994). Propagación de variaciones de baja frecuencia en la temperatura superficial del Pacífico nor-oriental. *Geofísica Internacional*, 33(3), 469-486.
- Hildebrand, D. (2014). Construyendo una nación meteorológicamente preparada. *Boletín de la Organización Meteorológica Mundial*, 63(2), 26-27.
- Hu, Z.-Z., Huang, B., Zhu, J., Kumar, A., McPhaden, M. A. (2018). On the variety of coastal El Niño events. *Climate Dynamics*. DOI: 10.1007/s00382-018-4290-4
- Hu, Shineng & Federov Alexey V. (2017) The extreme El Niño of 2015 - 2016: the role of westerly and easterly wind bursts and preconditioning by the failed 2014 event. *Climate Dynamics*. DOI: 10.1007/s00382-017-3531-2
- Huang, B., Liu C., Banzon V., Freeman E., Graham G., Hankins B., Smith T. & Zhang, H.-M. (2021). Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1. *Journal of Climate*, 34, 2923-2939. DOI: 10.1175/JCLI-D-20-0166.1
- Jacobson, Tess Wei-Ping, & Seager, Richard. (2025) Pacific Decadal Variability and Its Hydroclimate Teleconnections in CMIP6 Models. *Journal of Climate*, 38 (19). Retrieved from <https://par.nsf.gov/biblio/10650683>. <https://doi.org/10.1175/JCLI-D-24-0616.1>
- Ji, K., Yu, J.-Y., Li, J., Hu, Z.-Z., Tseng, Y.-H., Shi, J., et al. (2024). Enhanced North Pacific Victoria mode in a warming climate. *npj Climate and Atmospheric Science*, 7, 49. <https://doi.org/10.1038/s41612-024-00599-0>
- Jin, FF, Boucharel, J. & Lin, II. (2014) Eastern Pacific tropical cyclones intensified by El Niño delivery of subsurface ocean heat. *Nature* 516, 82–85 <https://doi.org/10.1038/nature13958>.

- Johnson, N. (2013). How Many ENSO Flavors can we distinguish? *Journal of Climate*, 4816-4827.
- Karnauskas, K. B., Busalacchi, A. J. (2009a). Mechanisms for the interannual variability of SST in the east Pacific warm pool. *J. Climate*, 22, 1375-1392.
- Karnauskas, K. B., Busalacchi, A. J. (2009b). The role of SST in the East Pacific Warm Pool in the Interannual Variability of Central American Rainfall. *Journal of Climate*, 22, 2605-2623.
- Kessler, W. S. (2006). The circulation of the eastern tropical Pacific: A review. *Progress in Oceanography*, 69, pp. 181-217. DOI: 10.1016/j.pocean.2006.03.009
- Kug, J.-S., Jin, F.-F. & An, S.-I. (2009). Two Types of El Niño Events: Cold Tongue El Niño and Warm Pool El Niño. *Journal of Climate*, 22(6), 1499-1515. DOI:10.1175/2008jcli2624.1
- Levine, A. F. Z. & McPhaden M. J. (2015). How the July 2014 easterly wind burst gave the 2015-2016 El Niño a head start, *Geophys. Res. Lett.*, 43, 6503-6510, DOI:10.1002/2016GL069204
- L'Heureux, M., Halpert, M., Bell, G. D. (2015). ENSO and the tropical pacific. [In the "State of the Climate in 2014"]. *Bul. Amer. Meteor. Soc.*, 96(7), S91-S93.
- Li W., Zhang P., Ye J., Li L., Baker P.A., (2011). Impact of two different types of El Niño events on the Amazon climate and ecosystem productivity. *J. of Plant Ecology*, 4(1-2).
- Li Z., Ding R., Mao J., Ren Z., (2023) Understanding the Driving Forces of the North Pacific Victoria Mode. *Journal of Climate* Vol 36 Issue 18 6547-6560 <https://doi.org/10.1175/JCLI-D-22-0951.1>
- Lyon, B. & Barnston, A. (2005). ENSO and the Spatial Extent of Interannual Precipitation Extremes in Tropical Land Areas. *American Meteorological Society*, 5095 - 5107.
- Maloney, E.D., Chelton, D.B., Esbensen, S.K. (2008) Subseasonal SST Variability in the Tropical Eastern North Pacific during Boreal Summer. *J. of Climate*, 21, 4149-4167
- Maloney, E. D. & Kiehl, J. T. (2002). MJO-related SST variations over the tropical eastern Pacific during Northern Hemisphere summer. *Journal of climate*, 15(6), 675-689.
- Marathe, S., Ashok, K., Swapna, P. & Sabin, T. P. (2015). Revisiting El Niño Modoki. *Climate Dynamics*, 45(11-12), 3527-3545. DOI:10.1007/s00382-015-2555-8
- Marengo, J., Alves, L., Alvala, R., Cunha, A., Brito, S. & Moraes, O. (2018). Climatic characteristics of the 2020 - 2016 drought in the semiarid Northeast Brazil region. *Anais da Academia Brasileira de Ciências*. DOI: <https://doi.org/10.1590/0001-3765201720170206>
- Martínez-Sánchez, J. N., Cavazos, T. (2014). Eastern Tropical Pacific hurricane variability and landfalls on Mexican coast. *Climate Research*, 58, 221-234. DOI: 10.3354/cr01192
- Martínez, R., Arévalo, J., Carrasco, G., Álvarez L., Bazo, J., Zambrano, E. (2015a). Northern South America and tropical Andes. [in "State of the Climate in 2014"]. *Bull. Amer. Meteor. Soc.*, 96(7), S178 -S179.
- Martínez, R., Pabón, D., Zambrano, E., Nieto, J. (2015b). ENSO Conditions during 2014: The Eastern Pacific perspective. [in the "State of the Climate in 2014"]. *Bul. Amer. Meteor. Soc.* 96(7), S181.
- McClatchie, S., Jacox, M.G., Ohman, M.D., Sala, L.M., Goericke, R., et al. (2016). State of the California Current 2015-16: comparisons with the 1997-98 El Niño. *CalCOFI Rep.*, 57, 57.
- Mejía, J. F., Yepes, J., Henao, J. J., Poveda G. (2021). Towards a mechanistic understanding of precipitation over the far eastern tropical Pacific and western Colombia, one of the rainiest spots on Earth. *Journal of Geophysical Research: Atmospheres*, 126(5), e2020JD033415. <https://doi.org/10.1029/2020JD033415>
- Misra, V., Dirmeyer, P. A., Kirtman, B. P., Juang, H. -M., & Kanamitsu, M. (2002). Regional Simulation of Interannual Variability over South America. *Journal of Geophysical Research (Atmospheres)*, 107, 3-1 3-16. <https://doi.org/10.1029/2001JD900216>
- Moreno - Rincon, J. L., Pabon- Caicedo, J. D. (2018). Sea surface temperature inter-annual variability in the northeastern tropical Pacific and its relationship with El Niño and La Niña conditions. IV International Conference on El Niño Southern Oscillation: ENSO in a warmer Climate, 16-18 October, 2018 - Guayaquil Ecuador, CIIFEN.
- NOAA. (2015a). Climate Diagnostics Bulletin, February 2015. https://www.cpc.ncep.noaa.gov/products/CDB/CDB_Archive_html/bulletin_022015/index.shtml
- NOAA. (2015b). Climate Diagnostics Bulletin, March 2015. https://www.cpc.ncep.noaa.gov/products/CDB/CDB_Archive_html/bulletin_032015/Tropics/tropics.shtml
- OCHA. (2014). Sequía en América Central. Reporte de situación No.1 (al 10 de diciembre de 2014). Oficina para la Coordinación de Asuntos Humanitarios (OCHA) de la Organización de las Naciones Unidas. Oficina de América Central, <https://reliefweb.int/report/guatemala/sequ-en-am-rica-central-report-de-situaci-n-no-01-al-10-de-diciembre-de-2014> (fecha de consulta 12 de noviembre de 2023).
- Pabón, J. & Martínez, R. (2016). Preface: Third ENSO Conference: findings and key messages. *Advances in Geoscience*, 91-93.
- Pabón, J., Montealegre, J. (2017). Los fenómenos de El Niño y de la Niña su efecto climático e impactos socioeconómicos. *Academia Colombiana de Ciencias Exactas, Físicas y Naturales*. Colección Jorge Álvarez Lleras, (34).
- Peng, Q., Xie, S.-P., Passalacqua, G. A., Miyamoto, A., & Deser, C. (2024). The 2023 extreme coastal El Niño: Atmospheric and air-sea coupling mechanisms. *Science Advances*, 10(12), eadk8646. <https://doi.org/10.1126/sciadv.adk8646>
- Raymond, D. J., Esbensen, S. K., Paulson, C., Gregg, M., Bretherton, C. S., Petersen, W. A., Cifelli, R., Shay, L. K., Ohlmann, C., & Zuidema, P. (2004). EPIC2001 and the Coupled Ocean-Atmosphere System of the Tropical East Pacific. *Bulletin of the American Meteorological Society*, 85(9), 1341-1354. <https://doi.org/10.1175/BAMS-85-9-1341>
- Rasmusson, E. & Carpenter, T. (1982). Variations in Tropical Sea Surface Temperature and Surface Wind Fields Associated with the Southern Oscillation / El Niño. *Monthly Weather Review*, 354-384. [https://doi.org/10.1175/1520-0493\(1982\)110<0354:VITSST>2.0.CO;2](https://doi.org/10.1175/1520-0493(1982)110<0354:VITSST>2.0.CO;2)
- Reynolds, R., Smith, T., Liu, C., Chelton, D., Casey, K., Schlax, M., (2007). Daily High-Resolution-Blended Analyses for Sea Surface Temperature. *Journal of Climate*, 20, 5473-5496. DOI: <https://doi.org/10.1175/2007JCLI1824.1>
- Rodríguez-Rubio, E. (2013). A multivariate climate index for the western coast of Colombia. *Advances in Geoscience*, 21-26. <https://doi.org/10.5194/adgeo-33-21-2013>
- Sáenz, F., Hidalgo, H. G., Muñoz, Á. G., Alfaro, E. J., Amador, J. A. y Vázquez Aguirre, J. L. (2022). Atmospheric circulation types controlling rainfall in the Central American Isthmus. *International Journal of Climatology*, 43(1), 197-218. DOI: <https://doi.org/10.1002/joc.7745>
- Salas, H., Poveda, G. Mesa, O. & Marwan, N. (2020) Generalized Synchronization Between ENSO and Hydrological Variables in Colombia: A recurrence Quantification Approach. *Frontiers in Applied Mathematics and Statistics* March 2020, 6, Article 3. <https://doi.org/10.3389/fams.2020.00003>
- Sentić, S., Bechtold, P., Fuchs-Stone, Ž., Rodwell, M., & Raymond, D. J. (2022). On the impact of dropsondes on the ECMWF Integrated Forecasting System model (CY47R1) analysis of convection during the OTREC (Organization of Tropical East Pacific Convection) field campaign. *Geoscientific Model Development*, 15(8), 3371-3385. <https://doi.org/10.5194/gmd-15-3371-2022>
- Shi, L., Ding, R., Hu, S. Mao J., Li J., Tseng Y., 2023 Joint effect of the North Pacific Victoria mode and the tropical Pacific on El Niño diversity. *Clim Dyn* 61, 151-168 (2023). <https://doi.org/10.1007/s00382-022-06550-4>
- Smith, N., Kessler, W. S., Cravatte, S., Sprintall, J., Wijffels, S., Cronin, M. F., ... Brunner, S. (2019). Tropical Pacific Observing System. *Frontiers in Marine Science*, 6. DOI:10.3389/fmars.2019.00031

- Song, H., A. J. Miller, S. McClatchie, E. D. Weber, K. M. Nieto & D. M. Checkley Jr. (2012). Application of a data assimilation model to variability of Pacific sardine spawning and survivor habitats with ENSO in the California Current System, *J. Geophys. Res.*, 117, C03009. DOI:10.1029/2011JC007302
- Takahashi, A., Montecinos, A., Goubanova, K. & Dewitte, B. (2011). ENSO regimes: Reinterpreting the canonical and Modoki El Niño. *Geophysical Research Letters*, American Geophysical Union, 1-5. <https://doi.org/10.1029/2011GL047364>
- Takahashi, K., Mosquera, K. y Reupo, J. (2014). El Índice Costero El Niño (ICEN): historia y actualización. *Boletín técnico: Generación de modelos climáticos para el pronóstico de la ocurrencia del Fenómeno El Niño*, 1(2), 8-9.
- Takahashi, K. & Dewitte, B. (2016). Strong and moderate nonlinear El Niño regimes. *Climatology Dynamics*, 1627-1645. <https://doi.org/10.1007/s00382-015-2665-3>
- Takahashi, K., Aliaga-Nestares, V., Avalos, G., Bouchon, B., Castro, A., Cruzado, L., Dewitte, B., Gutiérrez, D., Lavado-Casimiro, W., Marengo, J., Martínez, A. G., Mosquera-Vásquez, K., Quispe, Q. (2018). The 2017 coastal El Niño. *Bulletin of the American Meteorological Society*, 99(8), Special Issue "State of the Climate 2017", s210-s211. DOI:10.1175/2018BAMSStateoftheClimate.1
- Tang, S., Luo, J.-J., Chen, L., Yu, Y. (2022). Distinct Evolution of the SST anomalies in the Far Eastern Pacific between 1997/1998 and 2015/2016 Extreme El Niños. *Advances in Atmospheric Sciences*, 39, 927-942. <https://doi.org/10.1007/s00376-021-1263-z>
- Trenberth, K. (1997). The Definition of El Niño. *Bulletin of the American Meteorological Society*, 2771-2777. [https://doi.org/10.1175/1520-0477\(1997\)078<2771:TDOENO>2.0.CO;2](https://doi.org/10.1175/1520-0477(1997)078<2771:TDOENO>2.0.CO;2)
- Trenberth, K. & Smith, L. (2006). The Vertical Structure of Temperature in the Tropics: Different Flavors of El Niño. *Journal of Climate*, 4956-4970. <https://doi.org/10.1175/JCLI3891.1>
- Vaughan, C. & Dessai, S. (2014). Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework *WIREs Clim Change* 2014, 5, 587-603. DOI: 10.1002/wcc.290
- Wang, C. & D. B. Enfield. (2001). The tropical Western Hemisphere warm pool. *Geophys. Res. Lett.*, 28, 1635-1638. <https://doi.org/10.1029/2000GL011763>
- Wang, C. & Fiedler, P. C. (2006). ENSO variability and the eastern tropical Pacific: A review. *Progress in Oceanography*, 69, 239-266 <https://doi.org/10.1016/j.pocean.2006.03.004>
- Woodman, R. & Takahashi, K. (2014). ¿Por qué no llueve en la Costa del Perú (salvo durante El Niño)? *Boletín Técnico "Generación de modelos climáticos para el pronóstico de la ocurrencia del Fenómeno El Niño"*. Instituto Geofísico del Perú, Lima, Perú.
- Yepes, J., Poveda, G., Mejía, J. F., Moreno, L. & Rueda, C. (2019). CHOCO-JEX: A Research Experiment Focused on the CHOCO Low-level Jet over the Far Eastern Pacific and Western Colombia. BCHOCHO-JEX: A Research Experiment Focused on the Chocó Low-Level Jet over the Far Eastern Pacific and Western Colombia. *Bull. Amer. Meteor. Soc.*, 100, 779-796, <https://doi.org/10.1175/BAMS-D-18-0045.1>
- Zaba, K Rudnik, D. (2016). The 2014 - 2015 warming anomaly in the Southern California Current System observed by underwater gliders. *Geophysical Research Letters*. DOI: <http://dx.doi.org/10.1002/2015GL067550>
- Zhao, H., Raga, G. B. (2015). On the distinct interannual variability of tropical cyclone activity over the eastern North Pacific. *Atmósfera*, 28(3), 161-178. DOI: 10.20937/ATM.2015.28.03.02
- Zhong, W., Cai, W., Zheng, X.-T. & Yang, S. (2019). Unusual anomaly pattern of the 2015/2016 extreme El Niño induced by the 2014 warm condition. *Geophysical Research Letters*, 46. DOI: <https://doi.org/10.1029/2019GL085681>