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Multidecadal Fluctuations in the Observed ENSO-Tropical Cyclone Teleconnection

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Key Points:

- The observed impact of ENSO on tropical cyclone (TC) activity exhibits multidecadal fluctuations
- The ENSO-TC teleconnection was strong in the Atlantic from the 1980s to mid-2000s and strengthened over the North Pacific in recent decades
- The ENSO-TC teleconnection is stronger in the Atlantic and North Pacific basins during a positive Atlantic Multidecadal Oscillation

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

El Niño-Southern Oscillation (ENSO) is a skillful predictor for seasonal tropical cyclone (TC) activity in most TC basins. This study examines recent changes in the observed ENSO-TC teleconnection strength, as measured by ENSO modulation of hurricane frequency. We find that the ENSO-North Atlantic TC teleconnection fluctuated over time, with the strongest relationship occurring from the 1980s to the mid-2000s. In the western and eastern North Pacific, the ENSO-TC teleconnection has strengthened in recent decades. Periods with a strong ENSO-TC teleconnection are associated with more favorable environmental conditions for TCs, with higher values of genesis potential indices. Positive phases of the Atlantic Multidecadal Oscillation coincided with periods of strong ENSO-TC teleconnections in the Atlantic and North Pacific basins. A weaker Atlantic ENSO-TC relationship was associated with negative phases of the Pacific Decadal Oscillation and the North Atlantic Oscillation. This research reveals climate conditions that modulate ENSO's utility for seasonal TC prediction.

Plain Language Summary

El Niño-Southern Oscillation (ENSO) is a useful predictor for seasonal tropical cyclone (TC) activity in many basins. Here we found that the strength of the ENSO-TC teleconnection, represented as the correlation between ENSO and the number of hurricanes and accumulated cyclone energy, has changed in the historical record. The ENSO-TC teleconnection in the North Atlantic fluctuated over time, with a weak relationship during the 1960s and 1970s and a strong relationship during the 1980s to mid-2000s. Meanwhile, the ENSO-TC teleconnection strengthened in the North Pacific in recent decades, with strong teleconnections after the 1980s in the western North Pacific and after the 2000s in the eastern North Pacific. Periods of strong ENSO-TC teleconnections are associated with more favorable environmental conditions for TCs, including higher values of genesis potential indices and higher mid-tropospheric humidity, as well as positive phases of the Atlantic Multidecadal Oscillation. Additionally, the negative phase of the Pacific Decadal Oscillation leads to strong/weak ENSO-TC teleconnections in the eastern North Pacific and North Atlantic, respectively. Furthermore, a negative North Atlantic Oscillation is associated with a weak ENSO-North Atlantic TC teleconnection. This research highlights variations in ENSO's effectiveness for seasonal TC prediction.

1. Introduction

El Niño-Southern Oscillation (ENSO) has been used as a source of seasonal predictability for tropical cyclone (TC) activity for decades (e.g., Gray, 1984; Nicholls, 1979). ENSO's influence on North Atlantic (hereafter, Atlantic) TC activity was first suggested by Gray (1984), who found fewer hurricanes, TC days, and landfalling TCs during moderate-to-severe El Niño years compared to non-El Niño years. Since then, numerous studies have suggested that ENSO impacts Atlantic TC activity by generating anomalies in the Walker circulation (Goldenberg & Shapiro, 1996; Klotzbach, 2011; Patricola et al., 2014; Pielke & Landsea, 1999; Smith et al., 2007). During El Niño events, these circulation anomalies increase vertical wind shear (VWS) in the Atlantic, suppressing TC activity, while VWS weakens during La Niña. Similarly, El Niño generates warm tropospheric temperature anomalies over the Atlantic leading to increased stability and decreased potential intensity and TC activity, and vice versa for La Niña (Tang and Neelin, 2004).

ENSO also modulates TC activity in other basins (Lin et al., 2020). During El Niño, the tropics near the International Date Line become more favorable for TC genesis, leading to a westward shift of eastern North Pacific

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(ENP) TCs (Chu & Wang, 1997; Camargo, Emanuel, et al., 2007; Camargo, Robertson, et al., 2007; Camargo et al., 2008; Han et al., 2016) and a southeastward shift of western North Pacific (WNP) TCs (Chan, 1985; Chia & Ropelewski, 2002; Patricola et al., 2018; Zhao et al., 2020), more/less frequent TCs in the eastern/western WNP during El Niño events, and a weak positive correlation between ENSO and total WNP TC frequency. Moreover, VWS decreases and vorticity and surface ocean heat content increase over the North Pacific during El Niño events, leading to a more favorable TC environment in both the ENP (Balaguru et al., 2020; Boucharel et al., 2016; Chu & Wang, 1997; Jin et al., 2014; Murakami et al., 2017) and WNP (Camargo, Emanuel, et al., 2007; Camargo, Robertson, et al., 2007; Camargo & Sobel, 2005; Chan, 1985; Mei et al., 2019; Wang & Chan, 2002).

The ENSO-TC teleconnection strength can fluctuate over time. Gray (1984) noted that, while El Niño was related to weaker TC activity in the 1900–1983 period, the same relationship was not found for 1871–1899. Saunders et al. (2017) reported a long-term oscillation in the correlation between ENSO and Atlantic TC activity, likely not simply explained by observational quality changes. Moreover, Shi et al. (2024) suggested that future global warming could alter ENSO's modulation of WNP TC activity, turning it from a dipole of lower/higher TC activity in the western/eastern portion of the basin during El Niño to a monopole of greater TC activity in the basin. Girishkumar et al. (2015) noted that post-monsoon Bay of Bengal TC activity during La Niña events increased more during 1975–2006 than in 1950–1974, attributing this to changes in the Pacific Decadal Oscillation (PDO).

The PDO is the leading mode of multidecadal variability over the Pacific Ocean, with warm (cold) SSTAs over the tropical Pacific during its positive (negative) phase, and a spatial pattern like that of ENSO (Newman et al., 2016). The PDO modulates the occurrence of strong TCs over the WNP (Lee et al., 2012), TC days over the ENP and WNP (Scoccimarro et al., 2021), and TC frequency over Asia (Lee et al., 2021). The Interdecadal Pacific Oscillation (IPO), which is highly correlated with the PDO (Newman et al., 2016), also modulates TC activity, with a positive IPO leading to fewer/more TCs over the Atlantic/ENP (Li et al., 2015), and a negative IPO leading to a decrease in WNP TC activity (Zhao et al., 2018).

Atlantic TC activity is also subject to multidecadal variability, which has been linked to the Atlantic Multidecadal Oscillation (AMO) (Bell & Chelliah, 2006; Goldenberg et al., 2001; Landsea et al., 1999; Vitart & Stockdale, 2001). The AMO is a multidecadal oscillation of North Atlantic SSTs characterized by warm/cold anomalies in its positive/negative phase (Enfield et al., 2001; Schlesinger & Ramankutty, 1994). AMO variability may be driven by fluctuations in oceanic circulations as well as changes in anthropogenic aerosols (Murphy et al., 2017, 2021; Zhang et al., 2013). Atlantic TCs are more frequent during the positive AMO, due to a combination of warmer underlying SSTs leading to increased evaporation, greater mid-tropospheric humidity, and weaker VWS (Chylek & Lesins, 2008; Huang et al., 2023; Klotzbach, 2011; Vecchi & Knutson, 2008). Meanwhile, changes in the Walker circulation create environmental conditions that are less conducive for WNP TCs during the positive AMO (Huang et al., 2023). Atlantic SSTAs also affect interannual Pacific TC activity. During positive Atlantic Meridional Mode phases, North Atlantic warming strengthens the Walker circulation, shifting favorable WNP TC activity westward via VWS anomalies (Zhang et al., 2017).

Recent studies have suggested multidecadal variability in the ENSO-North Tropical Atlantic (NTA) SST relationship (Chen et al., 2022; Park & Li, 2019), possibly driven by the North Atlantic Oscillation (NAO) (Ding et al., 2023). This link is strengthened by global warming in simulations run as part of the Coupled Model Intercomparison Project, Phase 6 (CMIP6, Kim et al., 2024). As NTA warming favors Atlantic TC genesis, it is, like ENSO, a primary source of Atlantic TC predictability. Indeed, North Atlantic SSTAs and ENSO can exert compensating influences on Atlantic TCs (Klotzbach, 2011; Patricola et al., 2014).

These climate modes can significantly impact TC seasons. For example, the 2023 hurricane/typhoon season was above/below average over the Atlantic/WNP despite strong El Niño conditions due to record warm northern tropical Atlantic SSTs (Klotzbach et al., 2024; Zhao et al., 2024) and a negative Pacific Meridional Mode, with possible contributions from background global SST warming (Zhao et al., 2024).

Motivated by hurricane seasons that defied the typical ENSO-TC relationship and the potential for multidecadal variability to modulate the ENSO-TC teleconnection, we investigate changes in the observed ENSO-TC teleconnection strength, measured by hurricane frequency and accumulated cyclone energy, in the Atlantic and North Pacific basins, and examine how multidecadal modes of variability may support periods of strong or weak ENSO-TC teleconnections.

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2. Data and Methods

ENSO intensity is measured using three SST-based indices: (a) Niño 3.4 (Barnston et al., 1997), the mean SSTA relative to 1991–2020 over 5°N–5°S, 170°W–120°W; (b) Relative Niño 3.4 (rNiño3.4) (Oldenborgh et al., 2021), the difference between Niño 3.4 and the mean SSTA over all tropical oceans (20°S–20°N); and the (c) ENSO Longitude Index (ELI) (Williams & Patricola, 2018), which represents the average longitude of tropical Pacific deep convection and captures the different types of ENSO. Monthly SST observations are taken from three data sets to assess sensitivity: the 2° resolution NOAA Extended Reconstructed SST v5 (ERSSTv5; Huang et al., 2017a) and v6 (ERSSTv6, Huang et al., 2025); and the 1° resolution Hadley Center Sea Ice and Sea Surface Temperature Dataset (HadISST; Rayner et al., 2003).

We calculated the 15-year running correlation, centered on analysis window midpoints, between each ENSO index and two measurements of TC activity: seasonal accumulated cyclone energy (ACE; Text S1 in Supporting Information S1) (Bell et al., 2000), and the annual number of TCs that reached hurricane strength (Hur; maximum wind speed > 63 kt), calculated for January-December and July-June of each year in the Northern and Southern Hemisphere, respectively. The 15-year period was chosen to filter out high-frequency oscillations. ACE and hurricane frequency are less affected by technological advances that led to an artificial long-term increase in short-lived tropical storms frequency (Klotzbach et al., 2022; Landsea et al., 2010). Observed TC activity is based on data from the National Hurricane Center (Landsea & Franklin, 2013) and Joint Typhoon Warning Center (Chu et al., 2002), archived in the International Best Track Archive for Climate Stewardship (IBTrACS; Gahtan et al., 2024; Knapp et al., 2010). The period analyzed is restricted to higher-confidence data and varies by basin, defined in Klotzbach and Landsea (2015) (Text S2 in Supporting Information S1). A correlation value is deemed statistically significant if its absolute value exceeds the critical Pearson correlation threshold corresponding to the 90% confidence level, and weak otherwise.

Additionally, we assessed the relationship between TC activity and environmental variables commonly associated with TC development, including VWS, 850 hPa absolute vorticity, and multiple TC genesis indices (Text S1 in Supporting Information S1). These variables were calculated from the monthly, 0.25° horizontal resolution European Center for Medium-Range Weather Forecasts Reanalysis version 5 (ERA5; Hersbach et al., 2020). Variables with the greatest correlation with Hur or ACE were used to diagnose fluctuations in the ENSO-TC relationship. We also briefly compare our ERA5-based results with those obtained from the Japanese 55-Year Reanalysis (JRA-55; Kobayashi et al., 2015). We analyzed the differences in the environmental conditions during periods of strong/weak ENSO-Hur correlations, defined as periods when the Hur-rNiño3.4 correlation was significant/insignificant at the 90% confidence level. We also calculated the ENSO-Hur running correlation using synthetic TCs from the Columbia Hazard Model (CHAZ, Text S3 in Supporting Information S1) (Lee et al., 2018) downscaled from ERA5 for 1951–2019.

Finally, we examined several climate indices as potential drivers of ENSO-TC correlation variability including the: (a) NAO, based on the difference in normalized sea-level pressure between Lisbon and Reykjavik (Hurrell et al., 2003); (b) AMO (Enfield et al., 2001), defined as the detrended North Atlantic SST (0–60°N average); and (c) PDO, the leading detrended Pacific SSTAs pattern (20–90°N, Mantua, 1999; Zhang et al., 1997). High-frequency oscillations in the NAO, AMO, and PDO were removed using a 15-year running mean. Additionally, we analyzed atmospheric carbon dioxide (CO_2) concentrations from the Mauna Loa Observatory (Keeling et al., 1976; Thoning et al., 1989).

3. Results

The ENSO-TC teleconnection strength, as measured by the correlation between ENSO indices and TC activity, has varied over time across most TC basins. In the Atlantic, the ENSO-TC teleconnection was mostly insignificant (90% confidence level) in the early observational record, approaching near-zero correlation in the 1970s (Figure 1a). It strengthened from the 1980s to the mid-2000s before weakening slightly through ~2010, indicating notable low-frequency variability. The ENSO-TC teleconnection strengthened over time in the ENP and WNP, becoming significantly positive in the 1980s for the WNP (Figure 1b) and in the 2000s for the ENP (Figure 1c). In the South Indian Ocean as well as for the Australian region, TCs were negatively correlated with ENSO during the 1990s, but the relationship became insignificant in the 2000s (Figures 1e–1g). The teleconnection remained consistently insignificant in the North Indian (Figure 1d) and significant in the South Pacific (Figure 1f), throughout those basins' observational periods. These results are independent of TC activity measure, SST data

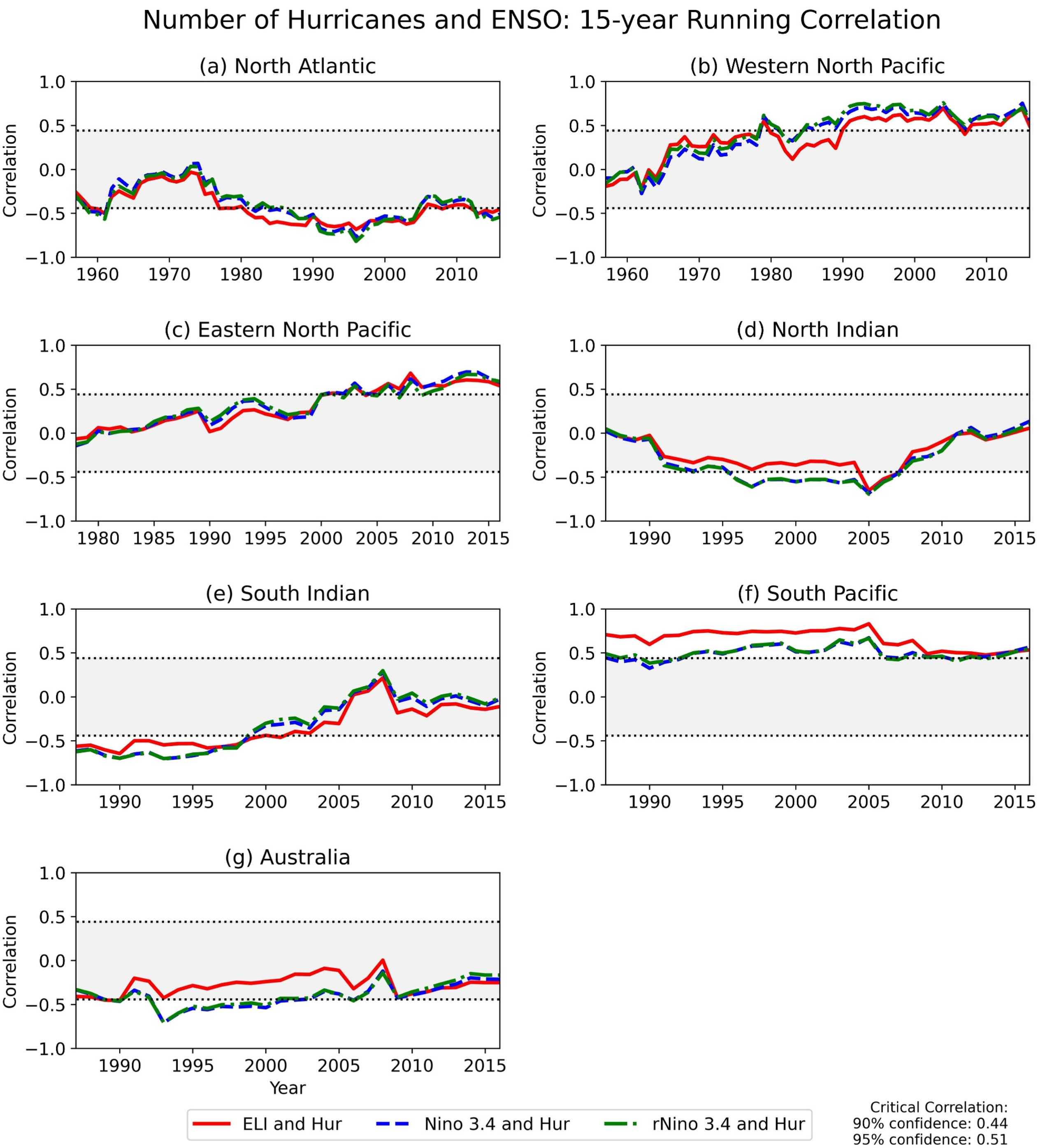

Figure 1. 15-year running correlation between ENSO and the number of hurricanes (Hur) in the (a) Atlantic, (b) WNP, (c) ENP, (d) North Indian, (e) South Indian, (f) South Pacific, and (g) Australian region. ENSO is represented by ELI (red solid), Niño 3.4 (blue dashed), and relative Niño 3.4 (green dot-dash). ENSO indices are averaged for August-September-October, October-November, and for December-January-February for panels (a–d) and (e–g), respectively. The critical correlation for 95% and 90% confidence levels is shown in the bottom. Insignificant correlations at the 90% level are shaded gray.

set, and ENSO index (Figures S1–S3 in Supporting Information S1). The remainder of this study focuses on ENSO-Hur teleconnection changes in the Atlantic, WNP, and ENP basins, which have longer records and clearer variations in ENSO-TC teleconnections. Note that positive trends in the ENSO-TC correlations also appear in the South Indian and Australian regions (Figure 1e), which could be explored in future studies.

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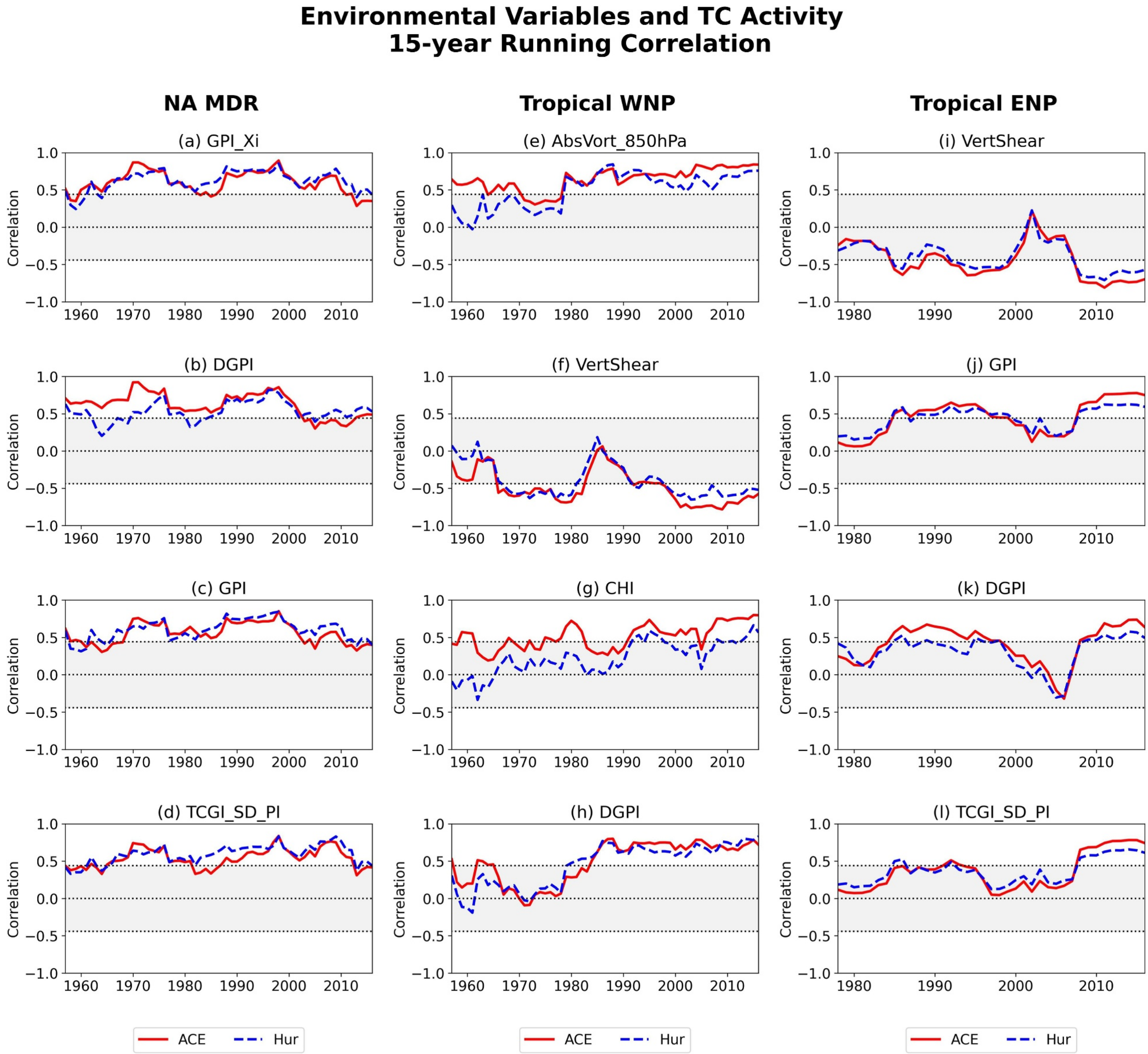

Figure 2. 15-year running correlation between environmental variables and TC activity, defined as Hur (dashed blue) and ACE (solid red) in panels (a–d) the North Atlantic, with the following variables averaged in the Main Development Region (10–20°N, 60–20°W): (a) GPI_Xi, (b) DGPI, (c) GPI, and (d) TCGI_SD_PI; (e–h) the WNP (10–20°N, 120–180°E) for (e) 850 hPa absolute vorticity, (f) VWS, (g) entropy deficit (CHI), and (h) DGPI; and (i–l) the ENP (10–20°N, 180–95°W) for (i) VWS, (j) GPI, (k) DGPI and (l) TCGI_SD_PI. Insignificant correlations at the 90% level are shaded gray.

Note that some amount of variability in the running correlation of two correlated series is expected (Gershunov et al., 2001), and the variability found here is within the expected for two time series of the same length (Text S4 and Table S1 in Supporting Information S1). However, we found statistically significant differences between the ENSO-TC teleconnection strength during the early versus late record in both the Atlantic and the WNP, suggesting that sampling cannot completely explain these findings (Table S2 in Supporting Information S1).

We also examined the correlation between TC activity and environmental variables and genesis potential indices averaged over August-September-October (ASO) to identify reliable proxies for TC activity (Figure 2 and Figures S4–S6 in Supporting Information S1). This allows us to assess whether the fluctuations in the ENSO-TC teleconnection strength are linked with fluctuations in TC environmental favorability. Given the greater reliability of the large-scale environment than TC observations earlier in the observational record, a similar temporal evolution of both the ENSO-TC and ENSO-environmental relationship would suggest that changes in ENSO-TC teleconnection strength are not an outcome of improved TC observations.

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In the Atlantic, the Genesis Potential Indices (GPI) GPI_Xi (Emanuel, 2010), GPI (Camargo et al., 2007b; Emanuel & Nolan, 2004), and Tropical Cyclone Genesis Index with saturation deficit and potential intensity (TCGI_SD_PI; Camargo et al., 2014; Tippett et al., 2011), averaged over the Main Development Region, are consistently positively correlated with ACE and Hur (Figures 2a–2d), indicating that they are strongly linked with Atlantic TC activity. Meanwhile, the extent that environmental variables represented WNP and ENP TC activity fluctuated over time. Despite these variations, 850 hPa absolute vorticity, dynamic GPI (DGPI; Murakami & Wang, 2022), and VWS are reliable predictors of WNP TC activity, especially after 1980 (Figures 2e–2h). Unexpectedly, entropy deficit (CHI) correlates positively with WNP ACE, despite typically suppressing TC development, making it an unreliable predictor (Figure 2g). Similarly, the strongest predictors of ENP TC activity are VWS, GPI, DGPI, and TCGI_SD_PI (Figures 2i–2l), although their reliability fluctuated over time. ENP TC activity's correlation with DGPI and VWS has briefly changed sign, likely due to outlier years (Figures 2i–2k).

ENSO's relationships with these variables fluctuated over time, mirroring the ENSO-TC relationship in the selected basins. In the Atlantic, ENSO's relationship with the selected variables mirrors the ENSO-TC relationship, weakening from 1960 to 1980 and strengthening afterward (Figures 3a–3d). In the WNP, ENSO's relationship with absolute vorticity, VWS, and DGPI strengthens over time (Figures 3f–3i), with the ENSO-DGPI correlation becoming significant in the 1980s. The ENSO-VWS relationship remained stable throughout our study period, but it became significant in the 1990s. In the ENP, ENSO's relationship with all selected variables strengthened, with all but DGPI becoming significant in the 2000s (Figures 3k–3n). While the ENSO-TC teleconnection in CHAZ shows weaker variability than observed, similar patterns appear in the Atlantic, ENP, and WNP, with their timing aligning closely (Figures 3e–3j and 3o). While reanalysis products vary in which environmental variables best reproduce TC activity in each basin (Figures S7–S9 in Supporting Information S1; Dirkes et al., 2023; Scoccimarro et al., 2024), similar relationships between ENSO and the environment are found using JRA-55 (Figures S10–S12 in Supporting Information S1). This suggests that the fluctuations in ENSO-TC teleconnection strength can be mostly reproduced from environmental conditions.

Next, we analyzed composites of the environmental conditions for years of strong and weak ENSO-TC teleconnections to understand how differences in the background state may support fluctuations in the ENSO-TC teleconnection strength (Table S3 in Supporting Information S1). We found that strong ENSO-TC teleconnections occur during periods with favorable environmental conditions for TCs. In the Atlantic and WNP, strong ENSO-TC teleconnection periods have warm SSTAs, high tropical mid-tropospheric humidity spanning 10–20°N, and positive DGPI anomalies over the regions where TCs occur (Figures 4c, 4d, 4e, and 4h). In the WNP, this coincides with higher sea-level pressure across the basin, except in the western WNP (110–150°E), where relatively lower pressure may favor TCs (Figures 4e–4h). Although environmental condition differences during strong/weak ENSO-TC teleconnections in the ENP are less distinct, strong ENSO-TC teleconnection periods have warmer-than-usual SSTAs over the US coast and negative VWS anomalies in the tropical ENP (15–30°N) that, despite drier mid-tropospheric humidity, generate positive DGPI anomalies over the central Pacific (Figures 4j–4l).

ENSO-TC teleconnections strengthen with warmer SSTAs in the Atlantic, ENP, and WNP (Figures 4a–4e and 4i). In the Atlantic, strong ENSO-TC teleconnections occur with a positive NAO-like sea-level pressure anomaly pattern over the Iberian Peninsula and Northern Europe. We compared the ASO-averaged AMO, PDO, and NAO during periods of strong and weak ENSO-TC teleconnections to understand how decadal and longer modes of variability may modulate the ENSO-TC teleconnection (Figure 5). We found that strong ENSO-TC teleconnections in the selected basins occur during the positive AMO (significant for 3/6 combinations of ENSO and TC variables in the Atlantic, and all combinations in the WNP and ENP). The negative phase of the PDO is associated with weak (strong) ENSO-TC teleconnections in the Atlantic (ENP). A negative NAO leads to weak ENSO-TC teleconnections in the Atlantic (significant for 4/6, all, and 3/6 combinations, respectively).

While climate variability can modulate the ENSO-TC teleconnection, disentangling the influence of global warming is challenging. The AMO index, though detrended, has shifted to its positive phase since the mid-1990s, while the PDO has trended negative since ~1990 (Figure 5d), meaning that both are highly correlated with ASO-averaged CO_2 concentration in our study period. Note that as these factors co-vary, we cannot distinguish between their influence in the observational record, and further studies are needed to determine their relative influence on the ENSO-TC teleconnection.

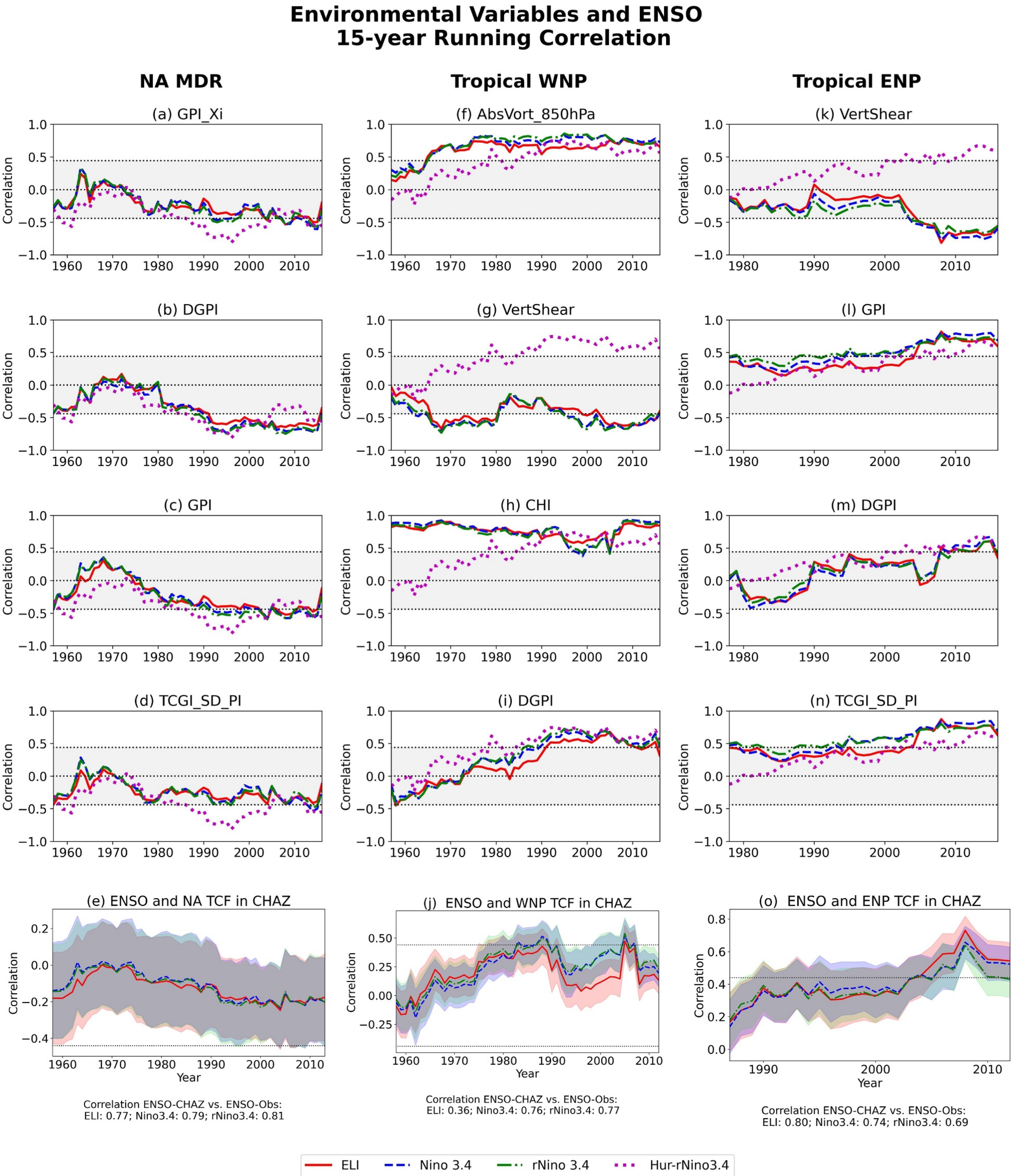

Figure 3. 15-year running correlation between environmental variables and ENSO, represented by ELI (solid red), Niño 3.4 (dashed blue) and rNiño3.4 (dashed-dot green) in panels (a–d) the North Atlantic for (a) GPI_Xi, (b) DGPI, (c) GPI, (d) TCGI_SD_PI; (f–i) the WNP for (f) 850 hPa absolute vorticity, (g) VWS, (h) CHI, (i) DGPI; and (k–n) the ENP for (k) VWS, (l) GPI, (m) DGPI, (n) TCGI_SD_PI. The correlation between rNiño3.4 and Hur is shown in each panel (magenta dots). Insignificant correlations at the 90% confidence level are shaded gray. (e, j, o) Running correlation between ENSO-Hur in CHAZ for the (e) Atlantic, (j) WNP, and (o) ENP, with shaded areas representing ensemble variability. Note that the *y*-axis limits are different for (e, j, o).

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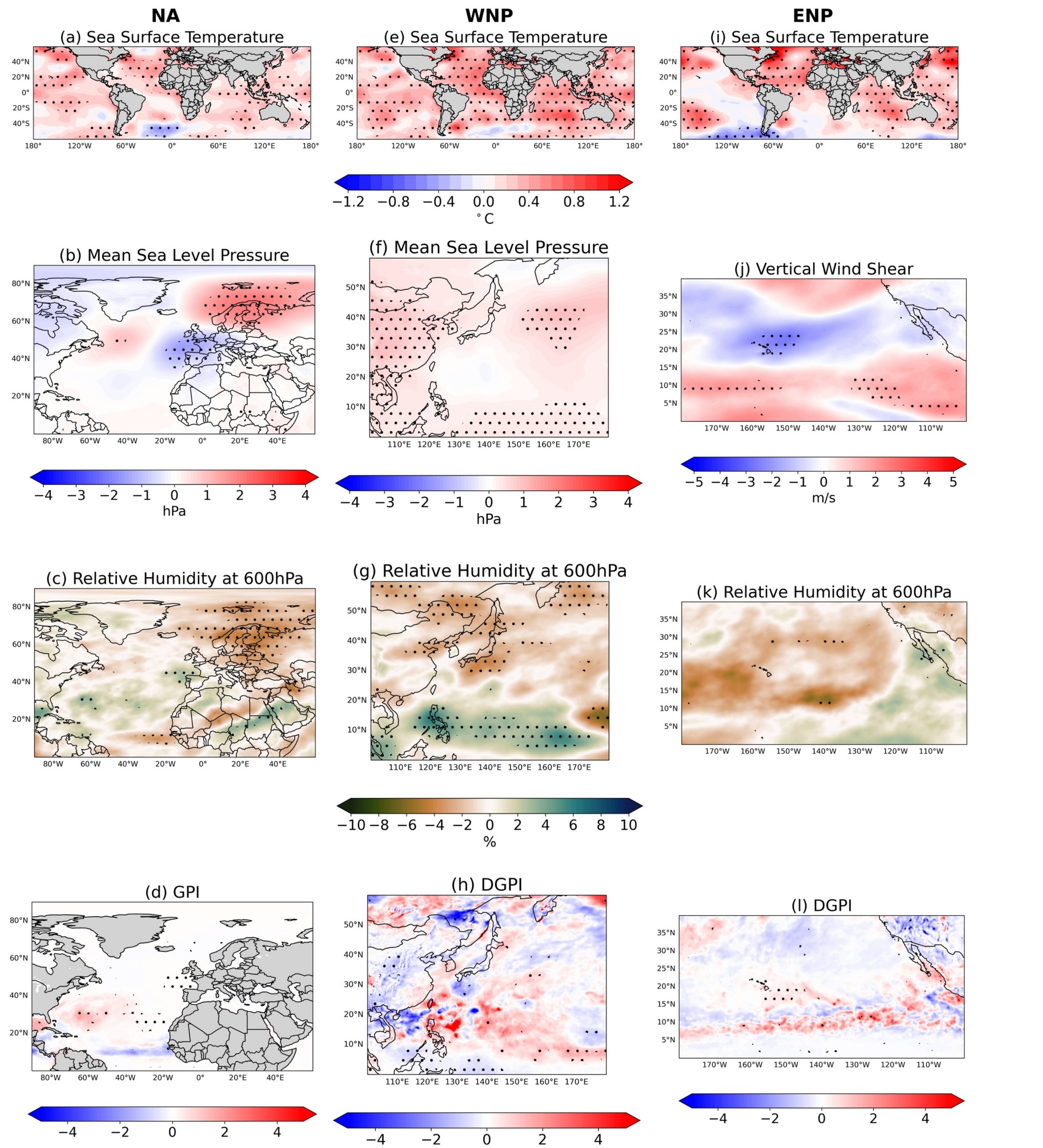

Figure 4. Difference between ASO-averaged environmental variables composited during years with strong minus weak ENSO-TC teleconnections, calculated for the North Atlantic for (a) SST (°C), (b) mean sea-level pressure (hPa), (c) relative humidity at 600 hPa (%), and (d) GPI; In the WNP for (e) SST (°C), (f) sea-level pressure (hPa), and (g) 600 hPa relative humidity (%), (h) DGPI; and in the ENP for (i) SST (°C), (j) VWS (ms^{-1}), (k) 600 hPa relative humidity (%), and (l) DGPI. Dots represent significant anomalies at the 95% confidence interval.

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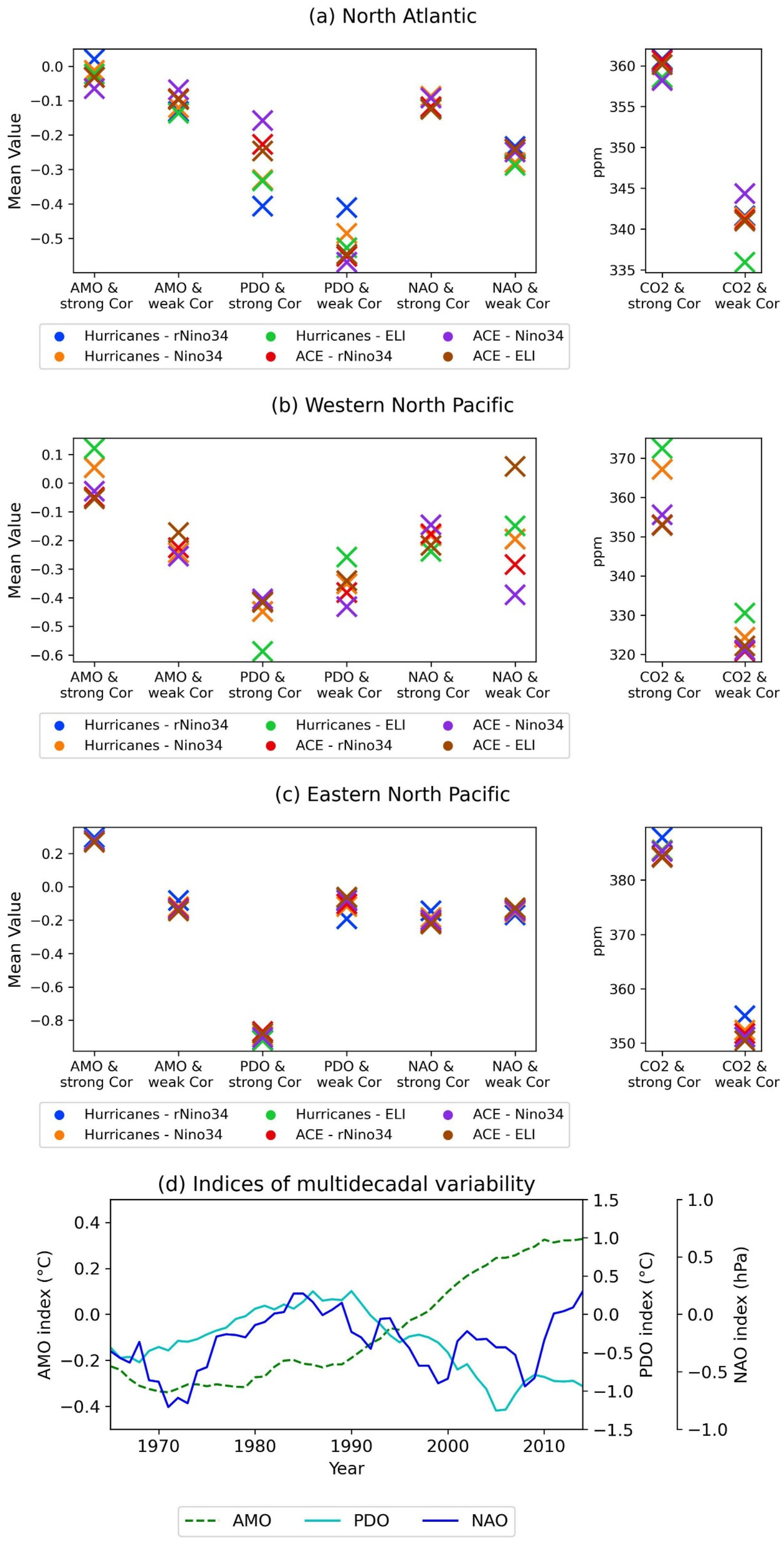

Figure 5. Mean value of AMO (°C), PDO (°C), NAO (hPa), and CO_2 (ppm), averaged during periods of strong and weak ENSO-TC teleconnections in the (a) North Atlantic; (b) western North Pacific; (c) eastern North Pacific. Points represent the different variables and indices used to calculate the ENSO-TC correlation. (d) 15-year running ASO-mean of the NAO, AMO, and PDO indices.

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4. Discussion and Conclusions

This study examines changes in the ENSO-TC teleconnection strength in the Atlantic, WNP, and ENP. The ENSO-Atlantic TC teleconnection strength fluctuated, being weak in the 1960s–1970s, strong in the 1980s-early 2000s, and weakening slightly since that time. In contrast, ENSO's influence on WNP and ENP TCs has strengthened in recent decades, becoming significant after the mid-1980s in the WNP and the 2000s in the ENP, despite noncanonical El Niño, which is less effective in modulating ENP TCs, becoming more frequent (Lee and McPhaden, 2010). We considered two non-physical explanations for the changes in the running correlation: sampling variability and changes in observational data quality. While these shifts are within the expected range for the running correlation of correlated timeseries, we found significant changes in the early versus late period correlation for both the Atlantic and the WNP, suggesting that these changes are not solely due to sampling variability. Similarly, these shifts align with variations in ENSO's relationship with TC environmental favorability, and cannot be explained only by observational improvements (Saunders et al., 2017). Moreover, the changes in ENSO-TC teleconnections are remarkably similar in all three ENSO indices analyzed, including the ELI, suggesting that the pattern cannot be attributed to changes in ENSO pattern or magnitude alone.

Periods of strong ENSO-TC teleconnections coincide with relatively favorable TC environments, such as a moist mid-troposphere, warm SSTAs, and increased DGPI. This aligns with studies that suggested a threshold of VWS above which TC development is suppressed (DeMaria et al., 1993; Wang et al., 2015; Zehr, 1992). When VWS was already elevated due to other climate mode influences, ENSO's influence on Atlantic TCs weakened (Patricola et al., 2014). Moreover, stronger ENSO-TC teleconnections are linked to a positive AMO, though attribution is not possible due to its recent covariance with rising CO_2 levels and other climate modes. Regardless, it may be that during the negative phase of the AMO, TC environmental favorability in the Atlantic is sufficiently decreased that a La Niña is insufficient to overcome the TC-unfavorable conditions of the negative AMO. Conversely, the impact of negative AMO and El Niño jointly may be similar to the impact of the negative AMO alone, leading to weaker Atlantic TC-ENSO teleconnections.

In addition, the negative PDO leads to stronger (weaker) ENSO-TC teleconnections in the ENP (Atlantic). Global warming may expand the area with greater WNP TC activity during El Niño in models (Shi et al., 2024), while multidecadal variability in the Atlantic, specifically the NAO, modulates the ENSO-NTA teleconnection (Ding et al., 2023), and thus Atlantic SSTs, with possible consequences for TC activity. However, as these climate modes and anthropogenic forcings co-vary, future research is needed to isolate each of their effects. The ENSO-Atlantic TC teleconnection is projected to remain strong or even strengthen further in the future (Lee et al., 2025; Mueller et al., 2024; Sena et al., 2022). Our findings suggest potential fluctuations in the strength of this teleconnection. Understanding these drivers is essential for improving seasonal hurricane forecasts.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

ERA5 (Hersbach et al., 2020, 2023) is provided by the Copernicus Climate Change Service at: https://cds.climate.copernicus.eu. NAO Index is (Hurrell et al., 2003) provided by the Climate Analysis Section, NCAR (Schneider et al., 2013), and is available at: https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based. PDO index was obtained at: https://www.ncei.noaa.gov/access/monitoring/pdo/. AMO index is available at: https://www1.ncdc.noaa.gov/pub/data/cmb/ersst/v5/index/ersst.v5.amo.dat. ERSSTv5 (Huang et al., 2017b) is available at: https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html. ERSSTv6 (Huang et al., 2025) is available at: https://www.ncei.noaa.gov/pub/data/cmb/ersst/v5/2023.ersst.v6/. HadISST is available at: https://www.metoffice.gov.uk/hadobs/hadisst/.

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