Statistical linkage between coastal El Niño–Southern Oscillation and tropical cyclone formation over the western North Pacific

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Abstract
This study investigates the modulation of tropical cyclone (TC) formation over the western North Pacific (WNP) by coastal El Niño–Southern Oscillation (ENSO). There is a significant inverse relationship between WNP TC frequency during July–October from 1961 to 2019 and simultaneous Niño 1+2 sea surface temperature anomalies. TC formation is significantly suppressed and enhanced over the subtropical and equatorial WNP during coastal El Niño, respectively, while TC formation exhibits opposite-signed anomalies during La Niña. This north–south dipolar pattern during coastal ENSO is distinct from the pattern observed in basin-wide ENSO events. Additional analyses show that coastal ENSO influences WNP TC formation through modulation of the large-scale environment. Changes in mid-level moisture and low-level vorticity appear to be the primary large-scale influences on TC formation during both coastal ENSO phases. These changes can be further linked to the anomalous large-scale circulation over the WNP during coastal ENSO.

KEYWORDS
coastal ENSO, tropical cyclone, western North Pacific

1 | INTRODUCTION

El Niño–Southern Oscillation (ENSO) is the leading tropical climate mode on interannual timescales and is generally characterized by an irregular oscillation between anomalously warmer (El Niño) and colder (La Niña) sea surface temperatures (SSTs) over the central and eastern tropical Pacific (Bjerknes, 1969; Timmermann et al., 2018; Wallace et al., 1998). ENSO events have widespread influences on weather and climate via modulation of the large-scale environment. For example, it is widely accepted that interannual variability of tropical cyclone (TC) activity over the western North Pacific (WNP), where approximately one-third of global TCs develop on average (Chan, 2005; Huang et al., 2021; Ma et al., 2020), is strongly modulated by ENSO (Emanuel, 2018). However, because of large inter-event discrepancies in ENSO's amplitude, spatial pattern and temporal evolution, TC activity over the WNP exhibits distinct features during different ENSO types.
Coastal El Niño can lead to a strengthening of the SST anomalies over the eastern equatorial Pacific (Philander, 1990; Rasmusson & Carpenter, 1982). Although canonical ENSO resulted in a southeast-northwest shift of WNP TC mean formation location, it only weakly impacted basin-wide WNP TC frequency (Chan, 1985, 2000; Lander, 1994; Saunders et al., 2000; Wang & Chan, 2002). Given that ENSO usually reaches its maturity during the boreal winter, TC frequency changes during various ENSO states have been investigated in the literature. For instance, Chen and Tam (2010) showed a weak correlation between basin-wide WNP TC frequency during boreal summer and autumn and the simultaneous canonical ENSO state. Tao et al. (2012) found that basin-wide WNP TC frequency during the active part of the TC season was not significantly altered in either canonical ENSO developing years or canonical ENSO decaying years. Since the early 2000s, ENSO events have been further classified into different flavors, primarily by their spatial patterns (Capotondi et al., 2020). In more recent years, ENSO Modoki has been identified and is characterized by having its largest SSTAs over the central equatorial Pacific (Ashok et al., 2007; Ashok & Yamagata, 2009; Kao & Yu, 2009; Kug et al., 2009; Yeh et al., 2009). Basin-wide WNP TC frequency is significantly related to the ENSO Modoki index, with more frequent TC formations in El Niño Modoki events due to the TC-favoring environment expanding farther northwestward in the WNP (Chen & Tam, 2010; Kim et al., 2011; Patricola et al., 2018).

Recently, several publications have identified a new ENSO category that has been termed “coastal El Niño”. This flavor of ENSO occurs less frequently than canonical El Niño or El Niño Modoki (Capotondi et al., 2020; Echevin et al., 2018; Garreaud, 2018; Hu et al., 2019; Lübbecke et al., 2019; Ormaza-González & Cedeño, 2017; Peng et al., 2019; Rodriguez-Morata et al., 2019; Takahashi et al., 2018; Takahashi & Martínez, 2019). Coastal El Niño is characterized by strong positive SSTAs over the far-eastern tropical Pacific near the South American coast and very weak SSTAs over the central-to-eastern equatorial Pacific. Compared to canonical El Niño or El Niño Modoki, which both feature a basin-scale warming over the tropical Pacific, coastal El Niño only exhibits a small-scale warming off of northern Peru. Through dynamical analyses and numerical simulations, previous work has studied the evolution and forcing of coastal El Niño, especially the boreal spring 2017 coastal El Niño episode. There do exist discrepancies in the literature on what was the leading trigger for the 2017 coastal El Niño (Echevin et al., 2018; Garreaud, 2018; Peng et al., 2019; Rodriguez-Morata et al., 2019). Coastal El Niño can lead to a strengthening of the Intertropical Convergence Zone south of the equator and anomalous northerlies across the equator in the far-eastern tropical Pacific, inducing intense rainfall and devastating floods in tropical western South America (e.g., Peru and Ecuador) (Capotondi et al., 2020). Nonetheless, it is still uncertain whether coastal El Niño has remote impacts on other weather and climate phenomena such as WNP TCs. Camargo (2018) reported below-normal WNP TC activity during the 2017 season. It would thus appear that WNP TC formation may be suppressed during coastal El Niño. Here we first examine this hypothesis and then evaluate how this suppression takes place.

This study focuses on TC formation rather than other TC metrics. The rest of this study is organized as follows. Section 2 introduces the data and methods. Section 3 documents the statistical relationship between coastal El Niño and WNP TC formation. Section 4 discusses the potential physical mechanism for how coastal El Niño modulates WNP TC formation. Section 5 summarizes this study.

2 | DATA AND METHODS

WNP TC best track data from 1961 to 2019 used in this study are from the International Best Track Archive for Climate Stewardship (IBTrACS) v04r00 (Knapp et al., 2010). Only TC cases simultaneously recorded by four warning agencies over the WNP, that is, the Joint Typhoon Warning Center, the Japan Meteorological Agency, the China Meteorological Administration and the Hong Kong Observatory, are considered here. By using these criteria, it reduces the uncertainty among data sources and enhances the robustness of the results (Song & Klotzbach, 2018). This method naturally excludes weak TCs, since the Japan Meteorological Agency does not record tropical depressions in its best track data. Meanwhile, the potential influences of the temporal evolution of observational technologies for weak TCs, as reported in Klotzbach and Landsea (2015), are also mini-mized by this method. The TC formation position is identified as the first record that is simultaneously listed by all four aforementioned agencies, as suggested by Song and Klotzbach (2018). The results that follow are not significantly changed if the TC formation position is regarded as when the TC first reaches tropical storm intensity in any one of the four best track datasets (figure not shown). We consider TCs generated during July–October (JASO), which account for ~69% of the annual total WNP TC number.

The TC genesis potential index (GPI) used in this study is the same as that used in Camargo, Emanuel, and Sobel (2007). They were the first to use the GPI to
investigate the ENSO-TC activity relationship. The GPI consists of four large-scale environmental variables: Maximum potential intensity (MPI), 600-hPa relative humidity (RH600), 850-hPa relative vorticity (VOR850) and 850-200-hPa vertical wind shear (VWS). These variables are all obtained from the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis of the global climate (ERAS; Hersbach et al., 2020), with a horizontal resolution of 0.25° × 0.25°.

Our study focuses on changes in JASO WNP TC frequency on interannual timescales, not synoptic timescales. On interannual and longer timescales, seasonal averages of environmental conditions have a much greater impact on modulating TC activity than daily or weekly averages do (Zhan et al., 2012). A majority of statistical seasonal TC forecasts thus apply seasonal mean atmospheric and oceanic states as predictors (Camargo, Barnston, et al., 2007; Klotzbach et al., 2019; Zhan et al., 2012). In addition, numerous previous studies have investigated the influence of ENSO-induced seasonal mean environmental factors on interannual changes in WNP TC activity (e.g., Camargo, Emanuel, & Sobel, 2007; Camargo & Sobel, 2005; Chen & Tam, 2010; Kim et al., 2011; Patricola et al., 2018). Based on the above reasons, all of the environmental variables analyzed in this study are averaged during JASO.

As noted in Takahashi et al. (2018), the seasonal Niño 1+2 SSTA index has been operationally applied to define a coastal El Niño event. However, significant Niño 1+2 SSTA can also be associated with other El Niño types, such as a canonical El Niño or a La Niña Modoki (Peng et al., 2019). In this study, we examine both coastal El Niño and coastal La Niña events. We use the JASO-averaged Niño 1+2 and Niño 3.4 SST indices from the National Oceanic and Atmospheric Administration Earth System Research Laboratory’s Physical Sciences Division. The SSTA is calculated from a 1961 to 2019 climatology. Coastal El Niño (La Niña) is defined when the Niño 1+2 SSTA is above (below) 0.5°C (−0.5°C), and the absolute value of the Niño 3.4 SSTA is less than 0.5°C. Our method is somewhat different from the definition of coastal El Niño used in Hu et al. (2019). Hu et al. (2019) defined a coastal El Niño event when both the original and ENSO-adjusted 3-month running mean Niño 1+2 SSTA indices were equal to or larger than one standard deviation and when these features persisted for at least three consecutive months. Hu et al. (2019) linearly regressed the Niño 1+2 SSTA onto the Niño 3.4 SSTA, while the residual time series was considered as the ENSO-adjusted Niño 1+2 SSTA. By comparison with Hu et al. (2019), our method excludes basin-wide ENSO events directly through the use of the Niño 3.4 SSTA magnitude being less than 0.5°C. Moreover, the coastal El Niño events identified in Hu et al. (2019) did not always occur during the TC-active season. Like previous TC-related publications (e.g., Kim et al., 2011; Patricola et al., 2018), we only focus on the ENSO state during JASO. Figure 1 displays the SSTA distribution during both coastal El Niño and coastal La Niña. As in previous studies (Capotondi et al., 2020; Echevin et al., 2018; Garreau, 2018; Hu et al., 2019; Lübbecke et al., 2019; Ormaza-González & Cedeño, 2017; Peng et al., 2019; Rodríguez-Morata et al., 2019; Takahashi et al., 2018; Takahashi & Martínez, 2019), coastal ENSO exhibits strong SSTAs over the Niño 1+2 region and weak SSTAs over the Niño 3 and Niño 4 regions. While there are differences in the coastal ENSO identification techniques employed by Hu et al. (2019) and this manuscript, the basic SSTA distributions are consistent.

Statistical significance of the correlation coefficients and anomalies are calculated using a two-tailed Student t-test.

**FIGURE 1** Composites of JASO SSTA during (a) coastal El Niño years and (b) coastal La Niña years. Black dots highlight anomalies significant at the 0.05 level. Orange and green boxes denote the Niño 1+2 and Niño 3.4 regions, respectively.
3 | STATISTICAL RELATIONSHIP

Consistent with previous studies (Chan, 1985, 2000; Chen & Tam, 2010; Lander, 1994; Saunders et al., 2000; Wang & Chan, 2002), we find a weak linkage between JASO WNP TC frequency and simultaneous Niño 3.4 SSTA \((r = -0.14, p = 0.30)\) from 1961 to 2019. We do, however, find a significant inverse relationship between JASO WNP TC frequency and simultaneous Niño 1+2 SSTA \((r = -0.32, p = 0.01)\).

In some publications (e.g., Camargo & Sobel, 2005), the WNP TC season is defined as June–November (JJASON). Consistent with the relationship during JASO, JJASON WNP TC frequency is weakly correlated with the simultaneous Niño 3.4 SSTA \((r = -0.03, p = 0.83)\), while it is significantly related to the simultaneous Niño 1+2 SSTA \((r = -0.28, p = 0.03)\). These results indicate that our findings do not materially change if a longer TC season is considered.

These above correlation results imply that coastal ENSO may have a greater impact on TC frequency than basin-wide ENSO. Table 1 lists the identified coastal ENSO years between 1961 and 2019, as well as the corresponding WNP TC frequency during JASO. During coastal El Niño years, the average frequency of JASO WNP TCs is 14.3, which is 4.1 less than the 1961–2019 long-term mean of 18.4 JASO TCs. The difference in TC frequency between coastal El Niño years and all years is statistically significant at the 0.01 level, meaning that basin-wide TC frequency is significantly reduced when coastal El Niño occurs. By comparison, during coastal La Niña years, the average frequency of JASO WNP TCs is 21.4, significantly greater (at the 0.05 level) than the long-term mean of 18.4 JASO TCs. This indicates that there is greater basin-wide TC frequency in coastal La Niña years.

Kim et al. (2011) showed that canonical El Niño (El Niño Modoki) induced a northwest-southeast (west–east) dipole in JASO TC genesis anomalies. During canonical El Niño, TC formation is significantly enhanced (suppressed) over the southeastern (northwestern) part of the WNP (Kim et al., 2011). The TC occurrence increase over the southeastern WNP is nearly balanced by a decrease over the northwestern WNP, resulting in a basin-wide TC frequency that is largely unchanged. During El Niño Modoki, the region with significantly enhanced TC formation over the eastern WNP is of a much greater areal extent than the region with significantly suppressed TC formation over the western WNP (Kim et al., 2011), inducing a notable increase in the basin-wide TC frequency. By comparison, the spatial distribution of TC genesis anomalies exhibits a north–south dipole in coastal El Niño years (Figure 2a). TC formation is generally suppressed north of 15°N, with two significant centers of TC reduction located in a small region spanning 15°–25°N, 120°–125°E, and a larger region spanning 15°–25°N, 140°–160°E. Coastal El Niño years generally enhance TC formation south of 15°N, with significant enhancement observed over the region spanning 0°–10°N, 140°–155°E. Compared with the climatological average, the number of TCs forming north of 15°N decreases by 6.3, while the number of TCs forming south of 15°N increases by 2.2. The magnitude of the former is significantly greater than that of the latter \((p = 0.02)\). These results imply that negative TC genesis anomalies cover a much larger portion of the WNP basin than positive anomalies do, leading to a basin-wide reduction in TC frequency during coastal El Niño.

The spatial distribution of TC genesis anomalies in coastal La Niña years almost mirrors that in coastal El Niño years (Figure 2b), with a pattern correlation coefficient of \(-0.55 (p < 0.01)\). Positive and negative TC genesis anomalies are primarily observed north and south of 10°N, respectively. We find significantly increased TC formation over the Philippine Sea and over the region spanning 15°–25°N, 140°–150°E. On average, the number of TCs forming north of 10°N increases by 3.1 from its climatology. By contrast, no regions have significant decreases in TC formation. The number of TCs forming south of 10°N only decreases by 0.1 from the long-term average, which is of significantly less magnitude than the TC occurrence increase north of 10°N \((p = 0.04)\). Compared with coastal El Niño, TC formation enhancement over the northern portion of the WNP during coastal La Niña plays a more dominant role than the small TC formation suppression over the southern portion of the WNP.

Additionally, when dividing the WNP into two halves, the average TC number decreases by 2.2 (1.8) east

Table 1: List of coastal El Niño and coastal La Niña years during JASO from 1961 to 2019, as well as the corresponding WNP JASO TC frequency

| Coastal El Niño | Coastal La Niña |
|-----------------|-----------------|
| Year | TC frequency | Year | TC frequency |
| 1969 | 13 | 1961 | 20 |
| 1976 | 14 | 1962 | 22 |
| 1979 | 15 | 1967 | 29 |
| 1983 | 15 | 1990 | 18 |
| 2006 | 16 | 1996 | 19 |
| 2014 | 13 | 2001 | 19 |
| 2013 | 23 |
| Mean | 14.3 | Mean | 21.4 |
of 140°E during coastal El Niño, while it increases by 2.2 (0.8) east (west) of 140°E during coastal La Niña. This indicates that the TC occurrence changes over the eastern and western WNP are almost in-phase during coastal ENSO, which is distinct from TC modulation observed during canonical El Niño or El Niño Modoki.

### 4 | POTENTIAL MECHANISM

The spatial patterns of WNP TC genesis anomalies during coastal El Niño and La Niña years (Figure 2a,b) are successfully captured by those of the GPI anomalies, except that the GPI anomalies are of the opposite sign over the East China Sea (Figure 2c,d). During coastal El Niño, negative (positive) GPI anomalies generally occur north (south) of 15°N, similar to the spatial structure of TC genesis anomalies (Figure 2c). The two centers of significantly decreased GPI correspond well to those with significantly suppressed TC formation. The region with significantly increased GPI is shifted slightly eastward from the region with enhanced TC formation. During coastal La Niña, significant positive GPI anomalies occur over nearly the same region where there are significant positive TC genesis anomalies (Figure 2d). These results imply that the modulation of WNP TC formation by coastal ENSO is primarily achieved through the modulation of large-scale environmental variables.

Figure 3 displays anomalies of the four environmental variables that constitute the GPI, including MPI, RH600, VOR850, and VWS, during coastal El Niño and La Niña years. During coastal El Niño, there are almost no significant MPI anomalies over the entire WNP (Figure 3a), possibly as a result of only minor SST changes across most of the basin in coastal El Niño events (Figure 1a). This result suggests that oceanic factors over the WNP only weakly respond to coastal El Niño. By contrast, within the latitudinal belt of 15°–25°N, reduced TC genesis anomalies (Figure 2a) correspond well with negative RH600 and VOR850 anomalies (Figure 3c,e). There are also positive RH600 and VOR850 anomalies south of 10°N and east of 130°E (Figure 3c,e), where enhanced TC genesis anomalies are observed (Figure 2a). Additionally, positive VWS anomalies are significant over the region spanning 15°–25°N, 120°–125°E, but are weak over the region spanning 15°–25°N, 140°–160°E (Figure 3g).
FIGURE 3  Anomalies of environmental variables during coastal El Niño years (left column) and coastal La Niña years (right column) for (a,b) MPI, (c,d) RH600, (e, f) VOR850 and (g,h) VWS. Regions bounded by black solid lines denote anomalies significant at the 0.05 level.
These results indicate that changes in VWS only influence TC formation in the former region.

During coastal La Niña, only very limited portions of the WNP have significant MPI and VWS changes (Figure 3b,h). As was found with coastal El Niño, RH600 and VOR850 changes are the dominant factors modulating the GPI distribution during coastal La Niña (Figure 3d,f). However, these two variables do not contribute equally when investigating different regions of the WNP. Over the region spanning 15°–25°N, 140°–150°E, there are...
significant positive RH600 and VOR850 anomalies (Figure 3d,f), both of which favor TC formation. Comparatively, over the Philippine Sea, VOR850 is significantly enhanced, while RH600 only changes slightly, meaning that increased VOR850 is likely the primary factor enhancing TC formation in this region.

In summary, JASO WNP TC formation as modulated by coastal ENSO is primarily due to changes in mid-level moisture (e.g., RH600) and low-level vorticity (e.g., VOR850), with other large-scale variables (e.g., SST, MPI, and VWS) having only minor impacts. Figure 4a,b illustrates how the phase of coastal ENSO modulates WNP TC formation. During coastal El Niño, over the subtropical WNP, there is a large-scale anomalous anticyclonic circulation centered at around 20°N, 150°E, accompanied by anomalous descending motion (Figure 4a). This anomalous circulation reduces not only cyclonic vorticity but also reduces upward vertical transport of moisture from the underlying ocean, both of which suppress TC formation. By comparison, over the tropical WNP, a low-level trough is observed that can provide additional cyclonic vorticity, favoring TC formation.

During coastal La Niña, an anomalous large-scale cyclone is observed over the subtropical WNP, associated with anomalous ascending motion (Figure 4b). This circulation anomaly is nearly the opposite of the anomaly observed during coastal El Niño. The increase in cyclonic vorticity and upward transport of moisture enhances TC formation during coastal La Niña. Also, during coastal La Niña, the tropical WNP is controlled by a large-scale deformation field, which only weakly affects vorticity. This leads to only minor changes in low-latitude WNP TC formation as modulated by coastal La Niña.

To further confirm the influence of coastal ENSO on the large-scale circulation, two sensitivity experiments were designed based on a high-resolution version of the Beijing Climate Center Climate System Model (BCC-CSM2-HR; Wu et al., 2021). Both experiments are driven by a climatological (1961–2019) atmospheric environment and an SST field with climatological means plus anomalies as shown in Figure 1a,b. During the coastal El Niño phase, a horizontal trough is observed south of 15°N (Figure 4a), while a large-scale cyclone is simulated over the same region (Figure 4c). Despite this difference, both patterns are favorable for TC formation. Furthermore, there are large-scale anticyclones within 15°–30°N in both the observations and the simulation, although the simulated anticyclone center is located more westward than the observed one (Figure 4a,c). TC formation is suppressed by both anticyclonic circulations. During the coastal La Niña phase, most of the WNP is covered by a large-scale cyclone in both the observations and the simulation (Figure 4b,d), which favors TC development. Overall, similar anomalous flow patterns are shown in the observed and simulated coastal ENSO phases, meaning that the impact of coastal ENSO on the environment can be verified by numerical simulations.

5 | SUMMARY

The modulation of WNP TC formation by coastal ENSO is investigated in this study. We find a significant inverse relationship between WNP TC frequency during JASO and simultaneous Niño 1+2 SSTA from 1961 to 2019. Coastal El Niño and coastal La Niña years are selected based on both Niño 1+2 and Niño 3.4 SSTA indices. There are significant SSTA changes over the Niño 1+2 region during coastal ENSO, while weak SSTA changes are observed over most of the remainder of the tropical Pacific. In general, JASO basin-wide TC frequency is significantly lower (higher) than the 1961–2019 long-term average during coastal El Niño (coastal La Niña). The spatial pattern of TC genesis anomalies exhibits a north–south dipole during coastal ENSO phases, which is different from the patterns during canonical ENSO or ENSO Modoki. During coastal El Niño (coastal La Niña), TC formation is suppressed (enhanced) over the subtropical WNP, while it is enhanced (suppressed) over the equatorial WNP.

The influence of coastal ENSO on TC formation can be explained by changes in large-scale environmental variables, as the spatial pattern of GPI anomalies is consistent with that of TC genesis anomalies. Among the four factors constituting the GPI, both MPI and VWS over the WNP are only weakly modulated during coastal ENSO events, indicating that they only play a minor role in modulating TC formation. By comparison, during both coastal ENSO phases, there are positive (negative) RH600 and VOR850 anomalies over the regions with enhanced (suppressed) TC formation. This result implies that coastal ENSO influences WNP TC formation primarily through modulation of mid-level moisture and low-level vorticity. Furthermore, the decreased (increased) RH600 and VOR850 results from anomalous anticyclonic (cyclonic) flow over the subtropical WNP during coastal El Niño (coastal La Niña).

This study only focuses on the simultaneous relationship between WNP TC formation and coastal ENSO. As reported in Hu et al. (2019), there are a wide variety of coastal ENSO events, with different durations and evolutions. In the future, we plan to investigate how different flavors of coastal ENSO events modulate WNP TC activity.

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AUTHOR CONTRIBUTIONS
Jinjie Song: Conceptualization; methodology; writing – original draft. Philip J. Klotzbach: Writing – review and editing. Yihong Duan: Funding acquisition; supervision.

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REFERENCES
Ashok, K., Behera, S.K., Rao, S.A., Weng, H. & Yamagata, T. (2007) El Niño Modoki and its possible teleconnection. Journal of Geophysical Research, 112, C11007.
Ashok, K. & Yamagata, T. (2009) Climate change: the El Niño with a difference. Nature, 461, 481–484.
Bjerknes, J. (1969) Atmospheric teleconnections from the equatorial Pacific. Monthly Weather Review, 97, 163–172.
Camargo, S.J. & Sobel, A.H. (2005) Western North Pacific tropical cyclone intensity and ENSO. Journal of Climate, 18, 2996–3006.
Camargo, S.J., Barnston, A.G., Klotzbach, P.J. & Landsea, C.W. (2007) Seasonal tropical cyclone forecasts. WMO Bulletin, 56, 297–309.
Camargo, S.J., Emanuel, K.A. & Sobel, A.H. (2007) Use of a genesis potential index to diagnose ENSO effects on tropical cyclone genesis. Journal of Climate, 20, 4819–4834.
Camargo, S.J. (2018) Tropical cyclones-western North Pacific basin. In “State of the Climate in 2017.”. Bulletin of the American Meteorological Society, 99, S120–S124.
Capotondi, A., Wittenberg, A.T., Kug, J.-S., Takahashi, K. & McPhaden, M. (2020) ENSO diversity. In: Santoso, A., Cai, W. & McPhaden, M. (Eds.) El Niño Southern Oscillation in a Changing Climate. Washington, DC: American Geophysical Union (AGU), pp. 65–86.
Chan, J.C.L. (1985) Tropical cyclone activity in the Northwest Pacific in relation to the El Niño/Southern Oscillation phenomenon. Monthly Weather Review, 113, 599–606.
Chan, J.C.L. (2000) Tropical cyclone activity over the western North Pacific associated with El Niño and La Niña events. Journal of Climate, 13, 2960–2972.
Chan, J.C.L. (2005) Interannual and interdecadal variations of tropical cyclone activity over the western North Pacific. Meteorology and Atmospheric Physics, 89, 143–152.
Chen, G. & Tam, C.-Y. (2010) Different impacts of two kinds of Pacific Ocean warming on tropical cyclone frequency over the western North Pacific. Geophysical Research Letters, 37, L01803.
Echevin, V., Colas, F., Espinoza-Morriberon, D., Vasquez, L., Anculie, T. & Gutierrez, D. (2018) Forcings and evolution of the 2017 coastal El Niño off northern Peru and Ecuador. Frontiers in Marine Science, 5, 367.
Emanuel, K.A. (2018) 100 years of progress in tropical cyclone research. Meteorological Monographs, 59, 15.1–15.68.
Garreaud, R.D. (2018) A plausible atmospheric trigger for the 2017 coastal El Niño. International Journal of Climatology, 38, e1296–e31302.
Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J. et al. (2020) The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146, 1999–2049.
Hu, Z.-Z., Huang, B., Zhu, J., Kumar, A. & McPhaden, M.J. (2019) On the variety of coastal El Niño events. Climate Dynamics, 52, 7537–7552.
Huang, X., Peng, X., Fei, J., Cheng, X., Ding, J. & Yu, D. (2021) Evaluation and error analysis of official tropical cyclone intensity forecasts during 2005–2018 for the western North Pacific. Journal of the Meteorological Society of Japan, 99, 139–163.
Kao, H.Y. & Yu, J.Y. (2009) Contrasting eastern Pacific and central Pacific types of ENSO. Journal of Climate, 22, 615–631.
Kim, H.-M., Webster, P.J. & Curry, J.A. (2011) Modulation of North Pacific tropical cyclone activity by three phases of ENSO. Journal of Climate, 24, 1839–1849.
Klotzbach, P.J. & Landsea, C.W. (2015) Extremely intense hurricanes: revisiting Webster et al. (2005) after 10 years. Journal of Climate, 28, 7621–7629.
Klotzbach, P.J., Blake, E., Camp, J., Caron, L.-P., Chan, J.C.L., Kang, N.-Y. et al. (2019) Seasonal tropical cyclone forecasting. Tropical Cyclone Research and Review, 8, 134–149.
Knapp, K.R., Kruk, M.C., Levinson, D.H., Diamond, H.J. & Neumann, C.J. (2010) The International Best Track Archive for Climate Stewardship (IBTrACS). Bulletin of the American Meteorological Society, 91, 363–376.
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, 1499–1515.
Lander, M.A. (1994) An exploratory analysis of the relationship between tropical storm formation in the western North Pacific and ENSO. Monthly Weather Review, 122, 636–651.
Lübbecke, J.F., Rudloff, D. & Stramma, L. (2019) Stand-alone eastern Pacific coastal warming events. Geophysical Research Letters, 46, 12360–12367.
Ma, Z., Fei, J., Lin, Y. & Huang, X. (2020) Modulation of clouds and rainfall by tropical cyclone’s coldwakes. Geophysical Research Letters, 47, e2020GL088873.
Ormaza-González, F.I. & Cedeño, J. (2017) Coastal El Niño 2017 or simply: the carnival coastal warming event? MOJ Ecology & Environmental Science, 2, 00054.
Patricola, C.M., Camargo, S.J., Klotzbach, P.J., Saravanan, R. & Chang, P. (2018) The influence of ENSO flavors on western North Pacific tropical cyclone activity. Journal of Climate, 31, 5395–5416.
Peng, Q., Xie, S.-P., Wang, D., Zheng, X.-T. & Zhang, H. (2019) Coupled ocean-atmosphere dynamics of the 2017 extreme coastal El Niño. *Nature Communications*, 10, 298.

Philander, S. G. (1990) El Niño, La Niña, and the Southern Oscillation. Academic Press, 293 pp.

Rasmusson, E.M. & Carpenter, T.H. (1982) Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *J. Climate*, 110, 354–384.

Rodríguez-Morata, C., Díaz, H.F., Ballesteros-Canovas, J.A., Rohrer, M. & Stoffel, M. (2019) The anomalous 2017 coastal El Niño event in Peru. *Climate Dynamics*, 52, 5605–5622.

Saunders, M.A., Chandler, R.E., Merchant, C.J. & Roberts, F.P. (2000) Atlantic hurricanes and NW Pacific typhoons: ENSO spatial impacts on occurrence and landfall. *Geophysical Research Letters*, 27, 1147–1150.

Song, J. & Klotzbach, P.J. (2018) What has controlled the poleward migration of annual averaged location of tropical cyclone lifetime maximum intensity over the western North Pacific since 1961? *Geophysical Research Letters*, 45, 1148–1156.

Takahashi, K., Aliaga-Nestares, V., Avalos, G., Bouchon, M., Castro, A., Cruzado, L. et al. (2018) The 2017 coastal El Niño. In “State of the Climate in 2017”. *Bulletin of the American Meteorological Society*, 99, S210–S211.

Takahashi, K. & Martínez, A. (2019) The very strong coastal El Niño in 1925 in the far-eastern Pacific. *Climate Dynamics*, 52, 7389–7415.

Tao, L., Wu, L., Wang, Y. & Yang, J. (2012) Influence of tropical Indian Ocean warming and ENSO on tropical cyclone activity over the western North Pacific. *Journal of the Meteorological Society of Japan*, 90, 127–144.

Timmermann, A., An, S.-I., Kug, J.-S., Jin, F.-F., Cai, W., Capotondi, A. et al. (2018) El Niño–Southern Oscillation complexity. *Nature*, 559, 535–545.

Wallace, J.M., Rasmusson, E.M., Mitchell, T.P., Kousky, V.E., Sarachik, E.S. & Von Storch, H. (1998) On the structure and evolution of ENSO-related climate variability in the tropical Pacific: lessons from TOGA. *Journal of Geophysical Research*, 103, 14241–14259.

Wang, B. & Chan, J.C.L. (2002) How strong ENSO events affect tropical storm activity over the western North Pacific. *Journal of Climate*, 15, 1643–1658.

Wu, T., Yu, R., Lu, Y., Jie, W., Fang, Y., Zhang, J. et al. (2021) BCC-CSM2-HR: a high-resolution version of the Beijing climate center climate system model. *Geoscientific Model Development*, 14, 2977–3006.

Yeh, S.W., Kug, J.S., Dewitte, B., Kwon, M.H., Kirtman, B.P. & Jin, F. F. (2009) El Niño in a changing climate. *Nature*, 461, 511–514.

Zhan, R.F., Wang, Y. & Ying, M. (2012) Seasonal forecasts of tropical cyclone activity over the western North Pacific: a review. *Tropical Cyclone Research and Review*, 1, 307–324.

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