Contrasting two spring SST predictors for the number of western North Pacific tropical cyclones

WANG Lei

Guangdong Province Key Laboratory for Coastal Ocean Variation and Disaster Prediction, College of Ocean and Meteorology, Guangdong Ocean University, Zhanjiang, China

ABSTRACT

Recent studies have revealed that two boreal spring sea surface temperature (SST) indices have potential to predict the number of western North Pacific (WNP) tropical cyclones (TCs) in the following peak typhoon season (June–October): the northern tropical Atlantic (NTA) SST, and the SST gradient (SSTG) between the southwestern Pacific and western Pacific warm pool. The interannual and interdecadal variations of NTA SST and SSTG and their relationships to the number of WNP TCs during 1950–2013 were compared. On the interdecadal timescale, SSTG showed better correlation with the number of WNP TCs than NTA SST. The interdecadal variation of NTA SST was closely associated with the Atlantic Multidecadal Oscillation, while that of SSTG was anti-correlated with the Central Pacific (CP) El Niño index at the interdecadal timescale. On the interannual timescale, both NTA SST and SSTG were modulated by two types of El Niño. The NTA SST revealed significant correlations with the number of WNP TCs beginning from the early 1960s; by contrast, SSTG showed significant correlations after the mid-1970s. Co-variability of NTA SST and SSTG existed after the late 1980s, induced by modulation from CP El Niño. The co-variability of these two spring SST predictors increased their prediction skill after the late 1980s, with enhanced correlation between the number of WNP TCs and the two predictors.

1. Introduction

Tropical cyclones (TCs) can cause severe damage to coastal regions, and therefore an accurate and timely forecasting of TC activity (e.g. frequency) is of vital importance. Understanding and predicting TC occurrence has been a topic of intense scientific interest.

Sea surface temperature (SST) is well known as an important factor influencing TC occurrence, and could potentially be used as a predictor. Recent studies (Zhan, Wang, and Wen 2013; Huo et al. 2015) have revealed two boreal spring SST predictors for western North Pacific (WNP) TCs: the meridional SST gradient (SSTG) in the western Pacific, and the northern tropical Atlantic (NTA) SST (Figure 1). These two predictors have the potential to predict the number of WNP TCs in the following peak typhoon season of June–October.

Zhan, Wang, and Wen (2013) identified that the SSTG between the southwestern Pacific (SWP) and western Pacific warm pool (WWP) in March–May (MAM) may be a good predictor for the number of WNP TCs, based on observations during 1980–2011. They showed that a positive SSTG anomaly induced unfavorable environmental conditions and greatly suppressed TC genesis. By extending the analysis back to 1951, Zhao et al. (2016) found that the relationship between SSTG and the number of WNP TCs was statistically significant only after the mid-1970s, due to influences from decadal shifts in the SST pattern in the central and eastern equatorial Pacific.
Wen (2013); (3) the Atlantic Multidecadal Oscillation (AMO) over the SWP (40–20°S, 160°E–170°W) and that over the WWP (8–16°N, 125–165°E), following Zhan, Wang, and Wen (2013); (3) the Atlantic Multidecadal Oscillation (AMO)

2. Data and methods

The numbers of WNP TCs in June–October during 1950–2013 were calculated using the TC data produced by the Shanghai Typhoon Institute of the China Meteorological Administration. To minimize subjectivity in identifying weak systems, only TCs with at least tropical storm intensity were included. Environmental variables were obtained from the NCEP–NCAR reanalysis (Kalnay et al. 1996). SST data were from the ERSST analyses (Smith et al. 2008).

The following climate indices were used: (1) the NTA SST index, defined as the area-averaged SST anomalies over (0°–25°N, 90°W–15°E), following Huo et al. (2015); (2) the SSTG index, defined as the difference between the SST over the SWP (40–20°S, 160°E–170°W) and that over the WWP (8–16°N, 125–165°E), following Zhan, Wang, and Wen (2013); (3) the Atlantic Multidecadal Oscillation (AMO) index, obtained from the Physical Sciences Division (http://www.esrl.noaa.gov/psd/data/timeseries/AMO/) and calculated as the detrended SST anomaly of the North Atlantic; (4) the Pacific decadal oscillation (PDO) index, derived as the leading principal component of North Pacific SST variability poleward of 20°N (http://research.jisao.washington.edu/pdo/PDO.latest); (5) the Niño3.4 index to track ENSO, defined by SST anomalies over (5°S–5°N, 170–120°W); and (6) eastern Pacific (EP) and central Pacific (CP) indices calculated using the regression-EOF method of Kao and Yu (2009) (http://www.ess.uci.edu/~yu/20SC/), to distinguish the EP and CP types of ENSO.

Following the method used in Wang and Lee (2009), interdecadal variability was obtained by performing a seven-year running mean on the detrended indices, and interannual variability was calculated by subtracting interdecadal signals from the detrended indices. We determined the statistical significance levels based on the two-tailed $p$ values using a Student’s $t$-test. To account for the reduction in the degrees of freedom for the running mean data, the effective degrees of freedom were calculated according to the method in Von Storch and Zwiers (1999) when estimating the significance of the correlation for the interdecadal time series.

3. Results

Note that the three key regions (NTA, WWP, and SWP) used to define the two predictors are located near the subtropical highs (SHs) (Figure 1): the southern flank of the northern Atlantic subtropical high (NASH) for the NTA and that of the WNP subtropical high (WNPSH) for the WWP, and the eastern side of the Australian high (AH) for the SWP. Thus, the SST variations in these three key regions might be influenced by the SHs through changing ocean surface winds and evaporation.

During 1950–2013, significant warming trends could be observed in the NTA SST (Figure 2(a)). Meanwhile, no apparent trends were observed for SSTG, which might be due to the offset effects of trends from the SWP and WWP. The number of WNP TCs showed a decreasing trend (Figure 2(e)), which may partly be associated with the NTA SST warming trend, considering the physical basis that a warming NTA could greatly suppress WNP TC genesis (e.g. Huo et al. 2015; Yu, Li et al. 2015).

On the interdecadal timescales, the correlation coefficient (CC) between NTA SST and SSTG was insignificant (CC = −0.008) during 1950–2013 (Table 1). However, if only the period after 1980 (1980–2013) was considered, significant positive correlation (CC = 0.726) could be found. Before 1980, the CC between NTA SST and SSTG on the interdecadal timescales was −0.564, which was insignificant at the 90% confidence level. The CCs with climate indices

![Figure 1. Climatology of MAM (March–May) SST (color shading; units: °C), 850-hPa wind (vectors; units: m s⁻¹), and SLP (contours; units: hPa) during 1971–2010.](http://example.com/image.jpg)
(Table 2) suggest that the interdecadal variability of NTA SST was significantly correlated with the AMO index; by contrast, SSTG was significantly anti-correlated with CP index on the interdecadal timescale. It is not surprising that the AMO could significantly modulate NTA SST, considering that the AMO is the leading mode of variability in the North Atlantic on the multidecadal timescale and that the NTA is a sub-domain of the North Atlantic. The influences of CP El Niño on SSTG may occur through the pathway of modulating the WNPSH and AH. Previous studies have noted significant influences of CP El Niño on the WNPSH (Paek et al. 2015) and Australian monsoon (Taschetto et al. 2010). SSTs in the WWNP and SWP could possibly be influenced by changing surface winds and evaporation associated with WNPSH and AH variations triggered by CP El Niño. CP-type ENSO has occurred more frequently in recent decades, especially after the early 1990s, which is considered to be linked with the AMO phase change in the early 1990s (Yu, Kao et al. 2015). Therefore, co-variation of NTA SST and SSTG on the interdecadal timescale could possibly have been induced when the AMO and the emergence of CP El Niño became linked in recent decades, as suggested by Yu, Kao et al. (2015). The correlations between NTA SST and SSTG on the interdecadal timescale were weak before 1980, which might be due to the weaker linkage between the AMO and CP El Niño in the earlier decades.

During the whole period of 1950–2013, the interdecadal variability of the number of WNP TCs was anti-correlated with that of SSTG (CC = −0.627), while the CC of the number of WNP TCs with NTA SST was insignificant (CC = −0.178) (Table 1). These results indicate that SSTG...
Table 2. Correlations between the two predictors (NTA SST and SSTG) and simultaneous climatic indices (PDO, AMO, Niño3.4, CP El Niño, and EP El Niño) on interdecadal timescales during 1950–2013.

| Predictor | PDO | AMO | Niño3.4 | CP El Niño | EP El Niño |
|-----------|-----|-----|---------|------------|------------|
| NTA SST   | -0.171 | 0.847 | 0.253  | 0.357      | -0.189     |
| SSTG      | -0.357 | 0.062 | -0.522 | -0.747     | 0.132      |

Notes: Bold values are statistically significant at the greater than 95% confidence level. NTA, northern tropical Atlantic; SSTG, SST gradient (between the southwestern Pacific and western Pacific warm pool); PDO, Pacific Decadal Oscillation; AMO, Atlantic Multidecadal Oscillation; CP, central Pacific; EP, eastern Pacific.

Table 3. Correlations between the two predictors (NTA SST and SSTG) and preceding winter (DJF) Niño indices (Niño3.4, CP El Niño, and EP El Niño) on the interannual timescale during 1950–2013.

| Predictor | Niño3.4 | CP El Niño | EP El Niño |
|-----------|---------|------------|------------|
| NTA SST   | 0.799   | 0.723      | 0.146      |
| SSTG      | 0.243   | 0.218      | 0.136      |

Notes: Bold values are statistically significant at the greater than 95% confidence level. NTA, northern tropical Atlantic; SSTG, SST gradient (between the southwestern Pacific and western Pacific warm pool); CP, central Pacific; EP, eastern Pacific.

Figure 3. Seventeen-year running correlations (e.g. the value in 1980 representing the correlation coefficient for 1980–1996) between (a) NTA SST (northern tropical Atlantic SST) and SSTG (SST gradient between the southwestern Pacific and western Pacific warm pool), and (b) the two predictors (NTA SST and SSTG) and the number of WNP (western North Pacific) TCs (tropical cyclones) based on the time series on the interannual timescale. Note: The horizontal dashed lines show the 90%, 95%, and 99% confidence levels.

The correlation between NTA SST and SSTG on the interannual timescale was not stationary (Figure 3(a)). No significant correlation between NTA SST and SSTG on the interannual timescale could be found before 1987, while significantly positive CCs above the 99% confidence level existed after 1988. So why were there different relationships between the two predictors in the earlier period (1950–1987; hereafter, P1) and the recent period (1988–2013; hereafter, P2)? To answer this question, regressions of SST and 850-hPa winds with respect to NTA SST and SSTG were examined during P1 and P2 (Figure 4). During P2, both SSTG and NTA SST warming seemed to be associated with the decaying of CP El Niño, with significant cold SST anomalies in the CP during June–August (JJA) (Figure 4(i) and (l)) preceded by significant CP warming during the preceding December–February (DJF) (Figure 4(g) and (j)). The association with the decaying CP El Niño was considered to induce the variability of the number of WNP TCs, while no significant correlation could be found for NTA SST.

On the interannual timescale, significant variations could be observed in both SSTG and NTA SST (Figure 2(d)). But what controlled the interannual variability of SSTG and NTA SST? Previous studies suggest that the preceding winter ENSO could significantly modulate NTA SST (e.g. Enfield and Mayer 1997; Wang 2005). However, no detailed investigation for SSTG variability has been carried out. Accordingly, we examined the relationship between the preceding winter ENSO, which is the dominant leading interannual mode, and the interannual variations of SSTG and NTA SST (Table 3). The CC between NTA SST and preceding winter Niño3.4 index was 0.799, confirming the significant influence of El Niño on NTA SST, as suggested in previous studies. But how did ENSO influence NTA SST? Two possible pathways were considered: one was via the Pacific–North America (PNA) teleconnection pattern, and the other via the Walker and Hadley circulations (WHC) transferring the Pacific SST signals to the Atlantic sector (Wang 2005). Both PNA and WHC anomalies triggered by El Niño could influence the NASH, and further modulate NTA SST by changing ocean surface winds and heat fluxes. To better distinguish different types of El Niño, CP and EP indices were examined. Results indicated significant correlation between NTA SST and CP index (CC = 0.723), but no significant correlations with EP index (Table 3). These results suggest that NTA SST may be more influenced by CP El Niño than EP El Niño.

The correlation between NTA SST and SSTG on the interannual timescale was not stationary (Figure 3(a)). No significant correlation between NTA SST and SSTG on the interannual timescale could be found before 1987, while significantly positive CCs above the 99% confidence level existed after 1988. So why were there different relationships between the two predictors in the earlier period (1950–1987; hereafter, P1) and the recent period (1988–2013; hereafter, P2)? To answer this question, regressions of SST and 850-hPa winds with respect to NTA SST and SSTG were examined during P1 and P2 (Figure 4). During P2, both SSTG and NTA SST warming seemed to be associated with the decaying of CP El Niño, with significant cold SST anomalies in the CP during June–August (JJA) (Figure 4(i) and (l)) preceded by significant CP warming during the preceding December–February (DJF) (Figure 4(g) and (j)). The association with the decaying CP El Niño was considered to induce the co-variability of NTA SST and SSTG during P2, as observed in Figure 3(a). During P1, different modulating processes were found. The increase of SSTG was linked to the development of EP cooling (Figure 4(b) and (c)), while NTA SST warming was associated with the decay of CP warming (Figure 4(d)–(f)). The cold SST anomalies in the CP were very weak in JJA during P1 (Figure 4(f)).
suggesting a slower decaying of CP warming during P1 compared with that during P2 (Figure 4(l)). Different types of ENSO evolutionary processes were found for SSTG and NTA SST warming during P1, so no significant co-variability between them could be found due to different modulating processes. To better represent the evolutionary process
of different types of ENSO, we defined a CP (EP) evolution index using the difference of JJA CP (EP) index and preceding DJF CP (EP) index. During P2, significant negative correlations were found between the CP evolution index (CPEI) and the two predictors (Table 4). By contrast, during P1, the EP evolution index (EPEI) was significantly anti-correlated with SSTG, while CPEI was closely associated with NTA SST. These correlation analyses support the conclusions obtained from the above regression analysis; that is, different Pacific El Niño evolutionary processes may have modulated the interannual variability of SSTG during P1 and P2. The center of the warm anomaly associated with El Niño events has moved from the EP to the CP in recent decades (e.g. Lee and McPhaden 2010). The factor modulating SSTG varies from the EP in P1 to the CP in P2, which might have been partly due to the more frequent occurrence of CP El Niño in recent decades. However, the details of the processes and mechanisms underpinning the changes of the EP/CP influences on SSTG have not been fully understood, and thus need to be investigated further in the future.

By comparing the regressed wind anomalies (Figure 4) and climatological mean winds (Figure 1), information on the variation of ocean surface heat fluxes due to wind speed change can be inferred. In the NTA, significant westerly wind anomalies from the preceding DJF to MAM (Figure 4(d), (e), (j), and (k)) decreased the climatological easterly wind, and thus likely further contributed to NTA SST warming by reducing evaporation. Analysis of local surface heat flux (e.g. Enfield and Mayer 1997) supports the dominant role played by surface wind changes in modulating NTA SST variations. Conversely, easterly wind anomalies in the WWP (Figure 4(e), (h), and (k)) increased the mean easterly winds, possibly generating SST cooling in this region by increasing evaporation. The wind anomalies in these two regions were likely closely associated with the change in intensity of the NASH and WNPsh, which were mainly triggered by El Niño. For the SWP, almost no significant wind anomalies were observed (Figure 4(b) and (h)), suggesting that SST anomalies may not have been dominantly forced by ocean surface fluxes. Ocean dynamic processes (i.e. ocean advection) may play more important roles in SST variation in the SWP. A detailed investigation of the ocean heat budget is needed in future work to reveal the full physical processes involved.

Next, we examined the relationships between the number of WNP TCs and the two predictors on the interannual timescale (Figure 3(b)). The correlations were not stationary. SSTG was significantly anti-correlated with the number of WNP TCs after the mid-1970s, but insignificantly before – consistent with the findings of Zhao et al. (2016). By contrast, NTA SST was significantly anti-correlated with the number of WNP TCs after the early 1960s, but insignificantly before. Chen et al. (2015) also suggested an intensified impact of tropical Atlantic SST on the WNP summer climate under a weakened Atlantic thermohaline circulation after the 1960s. However, Cao et al. (2016) found that the influence of NTA SST on the number of WNP TCs was significant after the late 1980s. The differences in these results are mainly due to the different datasets and analysis methods used. In Cao et al. (2016), only long-term trends were removed from the data, which included both interannual and interdecadal variations. However, only variation on the interannual timescale was considered in our study. Due to weak correlations between NTA SST and the number of WNP TCs on the interdecadal timescale before 1980 (Table 1), an analysis including the interdecadal signals would substantially reduce the CC between NTA SST and the number of WNP TCs, especially before 1980, as in the results of Cao et al. (2016). Our results suggest that NTA SST could be significantly anti-correlated with the number of WNP TCs after the early 1960s if only the interannual signals are considered (excluding interdecadal signals). Another major difference is that TCs in the South China Sea (SCS) were not considered in Cao et al. (2016), while all TCs in the WNP, including the SCS, were analyzed in our study. During P2, both NTA SST and SSTG showed an enhanced association with the number of WNP TCs, as compared with the situation during P1. As discussed above, both NTA SST and SSTG tended to vary at almost the same pace during P2, due to the modulation by CP El Niño. These results suggest that the co-variability of NTA and SSTG may increase their prediction skill with respect to the number of WNP TCs after the late 1980s, with enhanced correlations between them. Significant low-level anticyclonic atmospheric circulation anomalies were observed over the WNP in JJA during P2 (Figure 4(i) and (l)), which were considered to be associated with significant cold SST anomalies in the CP at the same time. These low-level anticyclonic anomalies were unfavorable for TC genesis and could have greatly reduced WNP TC numbers. Therefore, a strong association with significantly negative CCs could be observed between the number of WNP TCs and the two predictors during P2. The co-variation of the
two predictors was considered to be able to contribute cooperatively to low-level anticyclonic anomalies over the WNP. The anticyclonic circulation anomalies over the WNP during P1 were much weaker compared with those during P2, which would have greatly weakened the correlations between the number of WNP TCs and the two predictors before the late 1980s.

4. Conclusion

We compared two predictors (SSTG and NTA SST) and their relationships with the number of WNP TCs on both interannual and interdecadal timescales, with the aim to better understand and predict WNP TC occurrence.

On interdecadal timescales, NTA SST was closely associated with AMO index, while SSTG was negatively correlated with CP index. A certain degree of in-phase association between the interdecadal variability of NTA SST and SSTG tended to exist after 1980, which may have been induced by the linkage between the AMO and the emergence of CP El Niño in recent decades, as suggested by Yu, Kao et al. (2015). SSTG showed better correlation than NTA SST with the number of WNP TCs on interdecadal timescales.

On the interannual timescale, variations of NTA SST and SSTG were modulated by two types of El Niño. After the late 1980s, both NTA SST and SSTG warming were closely associated with the decay of CP El Niño, giving rise to co-variability of the two predictors. Before the late 1980s, although NTA SST warming was driven by CP El Niño, SSTG warming changed to become associated with EP La Niña development. Thus, there were no significant correlations between NTA SST and SSTG before the late 1980s due to different modulating processes. NTA SST was significantly correlated with the number of WNP TCs beginning from the early 1960s; by contrast, SSTG was significantly correlated with the number of WNP TCs after the mid-1970s. The co-variability of NTA SST and SSTG increased their prediction skill with respect to WNP TC numbers after the late 1980s, with enhanced correlation between the number of WNP TCs and the two predictors.

The variations of the two predictors were found to have possibly been influenced, to a considerable extent, by the various SHs. These SHs might induce SST anomalies by changing ocean wind speeds and evaporation, and the subsequently generated SST anomalies might then further influence the SHs via atmospheric responses to underlying SST anomalies (e.g. Wang, Xiang, and Lee 2013). These air-sea interactions between SHs (NASH, WNPSH, and AH) and SSTs in the three key regions (NTA, WWP, and SWP) need to be investigated further in future work.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was funded by the Guangdong Natural Science Foundation [grant number 2015A030313796]; the National Natural Science Foundation of China [grant numbers 41205026, 41476009, 41476010]; the Strategic Priority Research Program of the Chinese Academy of Sciences [grant number XDA11010104]; the National Program on Global Change and Air-Sea Interaction [grant number GASI-IPOV1-04]; the Knowledge Innovation Program of the Chinese Academy of Sciences [grant number SQ201208].

ORCID

WANG Lei http://orcid.org/0000-0002-9015-5422

References

Cao, X., S. F. Chen, G. H. Chen, and R. G. Wu. 2016. “Intensified Impact of Northern Tropical Atlantic SST on Tropical Cyclogenesis Frequency over the Western North Pacific after the Late 1980s.” Advances in Atmospheric Science 33 (8):919–930. doi:10.1007/s00376-016-5206-z.

Chen, W., J. Y. Lee, R. Lu, B. Dong, and K. J. Ha. 2015. “Intensified Impact of Tropical Atlantic SST on the Western North Pacific Summer Climate Under a Weakened Atlantic Thermohaline Circulation.” Climate Dynamics 45 (7): 2033–2046.

Enfield, D. B., and D. A. Mayer. 1997. “Tropical Atlantic Sea Surface Temperature Variability and Its Relation to El Niño-Southern Oscillation.” Journal of Geophysical Research 102: 929–945.

Huo, L., P. Guo, S. N. Hameed, and D. Jin. 2015. “The Role of Tropical Atlantic SST Anomalies in Modulating Western North Pacific Tropical Cyclone Genesis.” Geophysical Research Letters 42: 2378–2384.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, et al. 1996. “The NCEP/NCAR 40-Year Reanalysis Project.” Bulletin of the American Meteorological Society 77 (3): 437–471.

Kao, H. Y., and J. Y. Yu. 2009. “Contrasting Eastern-Pacific and Central-Pacific Types of ENSO.” Journal of Climate 22: 615–632.

Lee, T., and M. J. McPhaden. 2010. “Increasing Intensity of El Niño in the Central-Equatorial Pacific.” Geophysical Research Letters 37: L14603. doi:10.1029/2010GL044007.

Li, X., S. Yang, H. Wang, X. Jia, and A. Kumar. 2013. “A Dynamical-Statistical Forecast Model for the Annual Frequency of Western Pacific Tropical Cyclones Based on the NCEP Climate Forecast System Version 2.” Journal of Geophysical Research 118: 12061–12074.

Paek, H., J. Y. Yu, J. W. Hwu, M. M. Lu, and T. Gao. 2015. “A Source of AGCM Bias in Simulating the Western Pacific Subtropical High: Different Sensitivities to the Two Types of ENSO.” Monthly Weather Review 143: 2348–2362.

Smith, T. M., R. W. Reynolds, T. C. Peterson, and J. Lawrimore. 2008. “Improvements to NOAA's Historical Merged Land–Ocean Surface Temperature Analysis (1880–2006).” Journal of Climate 21: 2283–2296.

Taschetto, A. S., R. J. Haarsma, A. S. Gupta, C. C. Ummenhofer, K. J. Hill, and M. H. England. 2010. “Australian Monsoon Variability Driven by a Gill–Matsuno-Type Response to Central West Pacific warming.” Journal of Climate 23: 4717–4736.

Von Storch, H., and F. W. Zwiers. 1999. Statistical Analysis in Climate Research. New York, NY: Cambridge University Press.
Wang, C. 2005. “ENSO, Atlantic Climate Variability and the Walker and Hadley Circulations.” In The Hadley Circulation: Present, past and Future, edited by H. F. Diaz and R. S. Bradley, 173–202. Dordrecht: Kluwer Academic.

Wang, C., and S. K. Lee. 2009. “Co-variability of Tropical Cyclones in the North Atlantic and the Eastern North Pacific.” Geophysical Research Letters 36: L24702. doi: 10.1029/2009GL041469.

Wang, B., B. Xiang, and J. Y. Lee. 2013. “Subtropical High Predictability Establishes a Promising Way for Monsoon and Tropical Storm Predictions.” Proceedings of the National Academy of Sciences 110: 2718–2722.

Yu, J., T. Li, Z. Tan, and Z. Zhu. 2015. “Effects of Tropical North Atlantic SST on Tropical Cyclone Genesis in the Western North Pacific.” Climate Dynamics 46: 865–877.

Yu, J. Y., P. K. Kao, H. Paek, H. H. Hsu, C. W. Hung, M. M. Lu, and S. I. An. 2015. “Linking Emergence of the Central Pacific El Niño to the Atlantic Multidecadal Oscillation.” Journal of Climate 28: 651–662.

Zhan, R., Y. Wang, and M. Wen. 2013. “The SST Gradient between the Southwestern Pacific and the Western Pacific Warm Pool: A New Factor Controlling the Northwestern Pacific Tropical Cyclone Genesis Frequency.” Journal of Climate 26: 2408–2415.

Zhang, W., G. A. Vecchi, H. Murakami, G. Villarini, T. Rosati, and L. Jia. 2016. “Modulation of Western North Pacific Tropical Cyclone Activity by the Atlantic Meridional Mode.” Climate Dynamics. doi: 10.1007/s00382-016-3099-2.

Zhao, J., R. Zhan, Y. Wang, and L. Tao. 2016. “Intensified Interannual Relationship between Tropical Cyclone Genesis Frequency over the Northwest Pacific and the SST Gradient between the Southwest Pacific and the Western Pacific Warm Pool since mid-1970s.” Journal of Climate 29:3811–3830. doi:10.1175/JCLI-D-15-0729.1.