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ORIGINAL PAPER

The influence of sea-surface temperatures on Eastern North Pacific tropical cyclone activity

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Abstract The influence of sea-surface temperatures on six measures of tropical cyclone activity in the Eastern North Pacific is examined using historical sea-surface temperature and tropical cyclone data spanning from 1971 to 2002. Relationships are evaluated using methods of trend analysis, extreme year analysis, and bivariate correlation. Results suggest that in order to understand the climatological factors affecting topical cyclone activity in the Eastern North Pacific, the main development region must be divided into two sub-regions of development to the east and west of 112°W longitude. Increasing trends of sea-surface temperature are not accompanied by increasing trends in tropical cyclone activity. In the western development region, sea-surface temperatures are significantly correlated with all measures of tropical cyclone activity during extreme years. In this region, sea-surface temperatures are on average below the threshold for tropical cyclone development. In the Eastern development region, the only significant correlation with sea-surface temperatures is for the more intense measures of hurricane activity. In this region, sea-surface temperatures are on average above the threshold for cyclone formation. This leads to the hypothesis that the proximity to the cyclone formation temperature threshold in the WDR enhances the sensitivity of tropical cyclone activity to SSTs. This may have application to other tropical cyclone basins such as the North Atlantic.

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1 Introduction

Previous work focusing on the relationship between sea-surface temperatures (SSTs) and tropical cyclone (TC) activity indicates that on interannual and interdecadal timescales, changes in TC activity have been linked to fluctuations in SSTs (Shapiro and Goldenberg 1998; Steenhof and Gough 2008). In areas of higher SST, hurricanes are able to maintain their organization and intensify through strengthening of the lower level convergence zone (Kimberlain and Elsner 1998). In their study of Atlantic tropical cyclone formation, Shapiro and Goldenberg (1998) determined that although SSTs appear to be of secondary importance to wind shear when explaining fluctuations in hurricane formation, the necessary condition of pre-existing SST anomalies in areas of formation show that they play an active role in enhancing storm development. Emanuel (2005) suggested that hurricane dissipation power is highly correlated with tropical SSTs, reflecting well-documented climate signals including decadal oscillations in the North Atlantic and North Pacific, and global warming.

Empirical research (DeMaria and Kaplan 1994; Whitney and Hobgood 1997) and theoretical studies (Emanuel 1988) suggest that SSTs may also play a significant role in determination of the maximum potential intensity (MPI) of a tropical cyclone. In both the Atlantic (DeMaria and Kaplan 1994) and the Eastern North Pacific (Whitney and Hobgood 1997; Hobgood 1998), the maximum intensities of storms show a gradual increase with increasing SSTs. Therefore SSTs appear to act as an upper bound on the MPI of a storm but were not found to be the sole factor controlling intensity. Whitney and Hobgood (1997) also suggest that other environmental factors such as strong vertical wind shear, upwelling of colder waters, and factors affecting outflow temperature, may all play a role in the intensity that a storm can achieve. The extreme activity of 2004 and 2005 Atlantic hurricane seasons stimulated research on the influence of climate change and warming SSTs on hurricane activity (Emanuel 2005; Webster et al. 2005; Hoyos et al. 2006; Klotzbach 2006; Landsea et al. 2006; Michaels et al. 2006; Trenberth and Shea 2006).

Compared to other ocean basins, TC activity in the Eastern North Pacific (ENP) has been largely neglected in scientific research. Since the majority of TCs in the ENP spawn and disintegrate in open waters far from landmasses and ship travel, many went unnoticed until the advent of weather satellites in the 1960s. Unfortunately, this means that only 30 to 40 years of reliable meteorological data is available for the ENP (Henderson-Sellers et al. 1998). Yet in terms of genesis events per unit area and events per unit time, the Eastern Pacific Ocean is the most active region of TC formation on earth (Molinari et al. 2000).

The objective of this work is to determine whether there is evidence of a significant relationship between various measures of tropical cyclone activity and SSTs in the ENP. This is achieved through the analysis of historical data between 1971 and 2002. The study area encompasses the main development region (MDR) of tropical cyclogenesis between 10–20°N and 85–140°W. Following Collins and Mason (2000), who identified that hurricane activity for the entire ENP was strongly influenced by the dominance of activity in the east which was obscuring important results when investigating the region as one single entity, this work will divide the ENP into two major development regions. For reasons that will be identified in more detail below, these two regions have been defined as the Eastern Development Region (EDR), the area between 10–20°N and 85–112°W, and the Western Development Region (WDR), the area between 10–20°N and 112–140°W (Fig. 1).

2 Data and methodology

The tropical cyclone data used in this study were taken from the National Hurricane Center (NHC) Tropical Prediction Center's (TPC) best track files available online at http://www.nhc.noaa.gov/pastall.shtml. The files are composed of historical TC track data for the ENP dating back to 1949. The database provides 6-h interval recordings

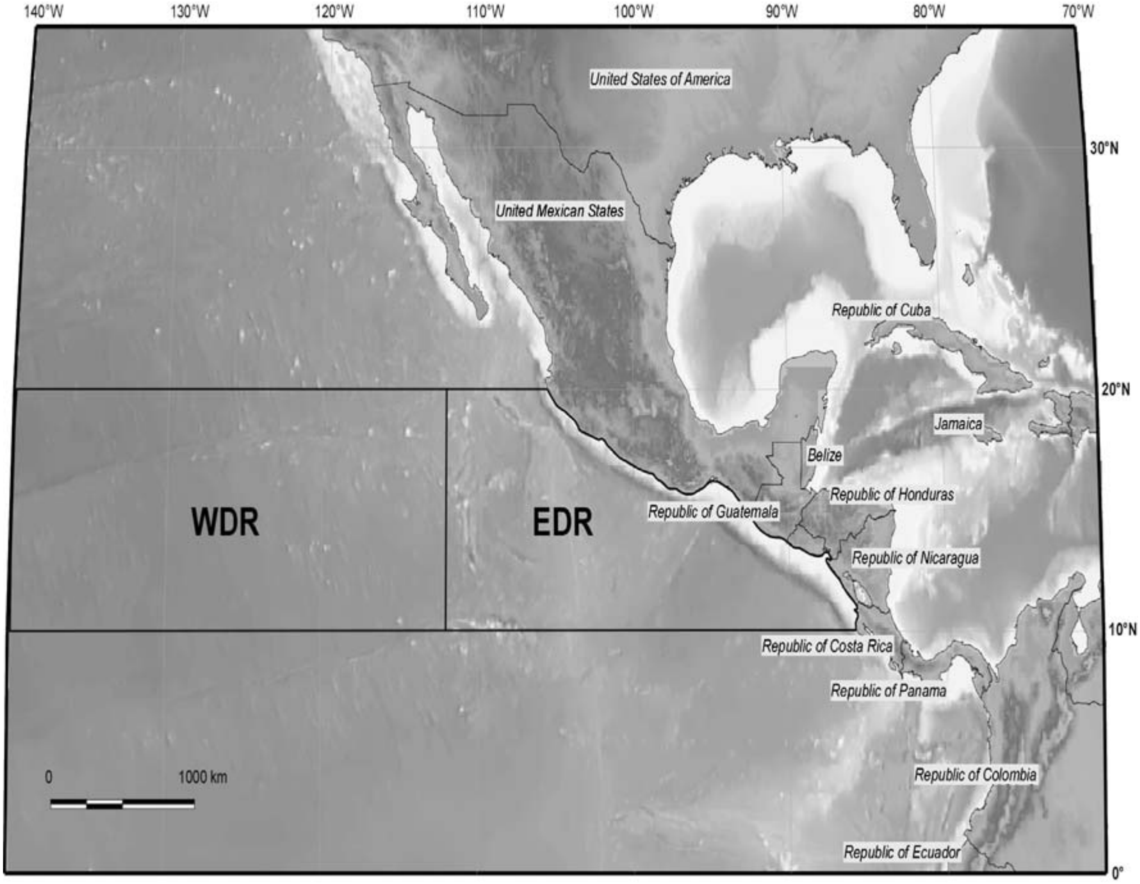

Fig. 1 Eastern and western tropical cyclone development regions

of storm data including: date and time, storm center location by latitude and longitude, maximum sustained surface winds, and central pressure. As defined by the NHC, the ENP tropical storm season extends from May 15th through November 30th. Therefore, storms in the best track database, which occurred before May or after November, were not included in this analysis. All storms initiating west of 140°W were also eliminated from the analysis, since they are not within the NHC's defined region of responsibility. Lastly, storms observed prior to 1971 were not included because the use of satellite imagery was not available until 1963 and the first few years of data appear unreliable (Whitney and Hobgood 1997; Steenhof and Gough 2008). Prior to 1971 no records of any major hurricanes existed, suggesting inadequate tracking techniques. After these eliminations, the final TC data set used in this study includes a total of 202 tropical storms (excluding those that developed into hurricanes) and 288 hurricanes, including 142 major hurricanes.

For the purpose of this analysis, data is divided into six different measures of TC activity according to the Net Tropical Cyclone (NTC) activity index. Tropical cyclone measures considered include: named storms (NS), named storm days (NSD), hurricanes (H), hurricane days (HD), major hurricanes (MH) and major hurricane days (MHD) (Gray et al. 2003). To increase the length of the dataset and to provide a more in-depth analysis of historical ENP storm seasons, values for these measures were produced on a monthly basis from May to November between 1971 and 2002. The counts of the measures of storm frequency (NS, H, MH) were determined by their presence in the best track data from one month to the next. The counts of the measures of storm duration (NSD, HD, MHD) were determined by summing the amount of 6-h periods for each month and then dividing by 4 to determine the total active storm days per month. Since the best track data is recorded at 6-h intervals, when a storm transformed from one classification to another (for example from a Category 2 hurricane, to a Category 3 hurricane) within an interval, 3 h were allotted to the total count for each measure of storm activity. This assumes that the change occurred exactly half way through the 6-h interval since there is no way of determining exactly when the increase in intensity occurred. In conjunction with this, the first (and last) recordings of storm activity were counted as a total of 3 h in duration for the particular measure of activity as there is, again, no way of determining the exact time during the 6-h interval that a storm achieved (or lost) official classification status. Table 1 shows the average values between 1971 and 2002 for the NTC activity measures of the EDR and the WDR.

Table 1 Tropical cyclone activity in the eastern and western development regions between 1971 and 2002

Measure of TC activity	Annual mean values between 1971 and 2002 in the EDR	Annual mean values between 1971 and 2002 in the WDR
Named storms	15.3	3.6
Named storm days	83.0	17.4
Hurricanes	8.7	1.3
Hurricane days	26.7	3.9
Major hurricanes	4.2	0.6
Major hurricane days	7.5	1.5

Historical SSTs for the designated MDRs were obtained from the Global Ocean Surface Temperature data set complied by the British Atmospheric Data Center available online at http://badc.nerc.ac.uk/home/. This electronic data set includes global mean monthly complete fields of SSTs on 1° latitude × 1° longitude grids, dating from 1871. For the purpose of this analysis, grid data was obtained for each development area and areal means were calculated.

Trend analysis is completed using the Kendall test for trends (Sprent 1989) to determine if statistically significant trends exist in annual SSTs as well as in measures of storm activity, through time. The presence of a consistent trend in time series data is determined by calculating Kendall's rank correlation coefficient, Tau (τ), which is based on pairwise ranks instead of actual values. Kendall's Tau is used to test for any monotonic dependence of Y on X and is resistant to outliers (Helsel and Hirsch 1991). Kendall's Tau is interpreted as a simple function of the probability that as x increases, y will increase (Kerridge 1975). A Tau value of 0 implies complete independence of the data set. Tau values between −1 and 0 imply a negative correlation and values between 0 and 1 imply a positive correlation. Tau values are considered statistically significant at $p \leq 0.05$. In addition, the Theil slope is calculated to determine an estimate of the magnitude of significant trends (Helsel and Hirsch 1991). The hurricane and temperature data were tested for autocorrelation.

For the extreme year analysis, tropical cyclone activity is extracted and pooled according to the most extreme years of SST between 1971 and 2002. Data is binned according to the five warmest and five coolest years of average SSTs for the entire region and subsequently for the EDR and WDR. Mean values of TC activity for the five warmest and five coolest years are calculated and Student's *t*-test is used to determine whether a significant difference in TC activity is present between groups of extreme years.

To determine whether there is a relationship between SSTs and TC activity, bivariate correlation is used. The Pearson product-moment correlation coefficient, r, is computed to give an index of the degree of the relationship between variables. The coefficient of determination, r^2, is further used to indicate the proportion of shared variance. For this analysis, SSTs and teleconnection indices act as independent (explanatory) variables and individual measures of storm activity (NS, NSD, H, HD, MH, MHD) are the dependent variables. The Pearson product-moment correlation requires normality in the data. This was tested using the Kolmogorov-Smirnov, Chi-square, and Shapiro-Wilks tests. These tests revealed that the higher-order measures of hurricane activity, especially in the WDR, were not normally distributed. This is a result of the large number of zero counts. To remedy this, the non-parametric Spearman rank correlation coefficient was also performed on the data.

3 Results and discussion

Figure 2 shows a plot of the spatial distribution of ENP tropical cyclones for all 31 years of analysis. The plot is based on the initial recorded coordinates of the storms as first identified and indicates a clear cluster of storm formation to the east of 112°W and a smaller more disperse group of storms forming to the west of 112°W. As determined by a Student *t*-test, statistically significant differences ($p \leq 0.05$) are evident to the east and west of 112°W in terms of total TC activity as well as SSTs. Overall, 81% of all storms formed in the EDR and the remaining 19% formed in the WDR. When classified according to strength, more hurricanes (261) than tropical storms (152) formed in the EDR, whereas more tropical storms (58) than hurricanes (40) formed in the WDR, which clearly indicates that the ENP cannot be treated as one homogenous development region. Climatological conditions for TC formation appear to be more favorable to the east of 112°W. For this reason, the longitude of 112°W was designated as the line of division between eastern and western regions of storm development in this work. These sub-regions of development will be compared to the entire development region spanning 10–20°N and 85–140°W, hereafter referred to as the main development region (MDR).

Results of the trend analysis indicated that no statistically significant temporal trends were present for any measure of TC activity in either development region. The TC data was not autocorrelated. However, results do indicate that SSTs in both the EDR and the WDR increased significantly between 1971 and 2002. However, the SST data was weakly autocorrelated for the MDR and WDR and thus the significance of the weak temporal trend is questionable. Figure 3 shows the time series of annual trends of seasonally averaged SSTs for both development regions, along with their resulting Theil slope values. The magnitude of the increase in the WDR was greater by approximately 0.01°C per year. The reason for this difference is presently unknown, but may be the result of the weak autocorrelation found in the WDR but not in the EDR.

Tables 2, 3, and 4 display binned storm data sets from the extreme year analysis of the MDR, EDR, and WDR, respectively. Data is grouped according to the five warmest and five coldest seasonally averaged SST years. Bold values in Tables 2 through 5 indicate results that are significant at $p \leq 0.05$. Results of the extreme year analysis illustrate that there are strong and statistically significant relationships between the difference of averaged warmest and coldest SSTs years for all measures of TC activity in the WDR. Conversely, the results for the EDR only indicate significant relationships between averaged extreme year differences for the measures of MH and MHD. When comparing all three tables it is clear that these results are only evident when the MDR is subdivided into eastern and western development regions. Extreme year analysis results

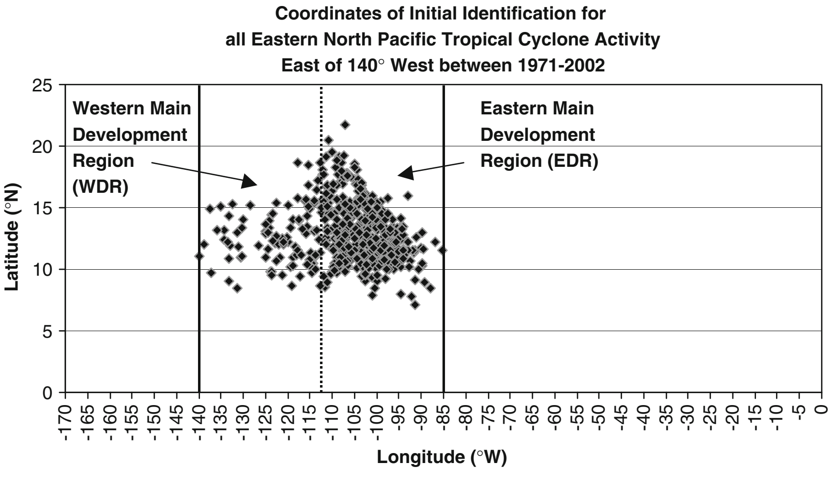

Fig. 2 Longitudinal distribution of initial disturbance locations for all TC activity in the ENP between 1971 and 2002

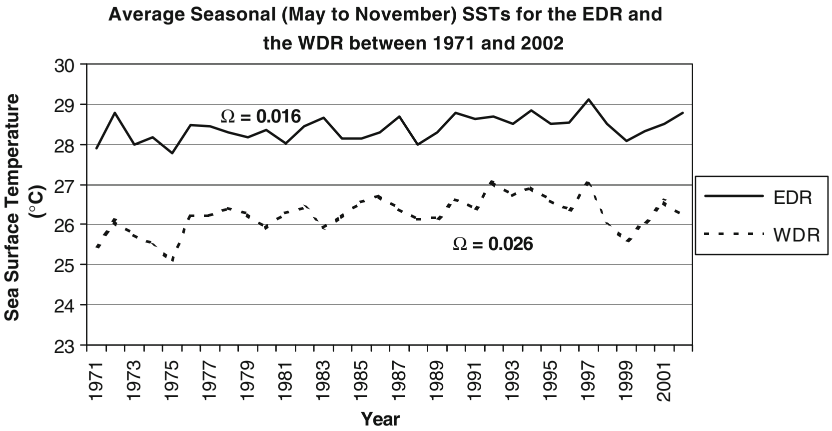

Fig. 3 Time series of SST in the EDR and WDR were found to have a significantly increasing trend through time, as indicated by the Kendall test for trends. The Theil slope (Ω) values indicate the magnitude of the trend in °C/year

for the MDR show significant relationships for the same storm measures as those of EDR. A likely explanation for this is the fact that the majority of TC activity in the ENP, and more specifically that the majority of MH and MHD activity, occurs within the EDR. Again, this suggests that significant differences in SSTs and their importance or lack of importance with regards to TC activity in different parts of the MDR, would have been overlooked if the development region was not subdivided for analysis. These results also suggest that the proximity to the tropical cyclone formation threshold (26.5°C) increases the sensitivity of tropical cyclone formation to SSTs. The WDR's SSTs are near this threshold whereas the EDR are well above.

We note that for the MDR analysis, 3 of the 5 years are El Nino years, 4 of 5 for EDR and 3 of 5 for WDR. ENSO can have two effects on hurricane activity. The first as illustrated here, the increase in SSTs during those year and the second is the reduction in wind shear, which allows for greater development of hurricanes. Latif et al. (2007) explore this relationship and suggest that the increased SSTs generate the decreased wind shear.

Table 5 displays the results of a bivariate correlation analysis for all measures of TC activity and seasonally averaged SSTs in all three development regions. All results are significant with a *p*-value at $p \leq 0.05$. The bivariate correlation analysis clearly indicates that there is a significant and positive relationship between SSTs and all measures of TC activity between 1971 and 2002. However, when the region is subdivided into eastern and western development regions, it is again evident that TC activity is different between the two. The most important aspect of these results appears in the degree of association between variables as indicated by the resulting Pearson correlation coefficients. The strongest degrees of association are found in the MDR results. When split, the WDR displays stronger degrees of association between SST and TC measures than

Table 2 Extreme year analysis results for SSTs in the MDR between 1971 and 2002

Five warmest years	SST average (May-Nov)	NS	NSD	H	HD	MH	MHD
1997	**27.9**	19	117.8	9	33.5	**7**	**15.0**
1994	**27.7**	21	128.6	12	34.8	**5**	**18.0**
1992	**27.7**	29	187.0	17	61.3	**10**	**20.3**
1990	**27.5**	25	164.2	16	58.3	**6**	**21.0**
1993	**27.4**	16	98.3	11	41.3	**8**	**13.1**
Average/total	**27.6**	110	695.8	65	229.1	**36**	**87.3**
Five coldest SST	SST average (May-Nov)	NS	NSD	H	HD	MH	MHD
1975	**26.2**	20	88.4	9	25.9	**4**	**5.5**
1971	**26.4**	23	117.5	14	38.5	**6**	**11.8**
1974	**26.6**	34	165.7	19	50.9	**6**	**9.8**
1999	**26.6**	9	58.5	6	23.5	**2**	**5.8**
1973	**26.6**	17	77.5	8	28.5	**3**	**7.3**
Average/Total	**26.5**	103	507.6	56	167.3	**21**	**40**
Student's t-test p value for difference between warmest and coldest years	**4.8E-06**	0.39	0.08	0.27	0.07	**0.02**	**1.0E-03**

Bolded values are statistically significant ($p<0.05$)

Table 3 Extreme year analysis results for SSTs in the EDR between 1971 and 2002

Five warmest SST	SST average (May-Nov)	NS	NSD	H	HD	MH	MHD
2002	**28.8**	15	71.0	7	19.3	6	**8.5**
1997	**29.1**	14	98.0	8	31.3	6	**13.0**
1994	**28.8**	11	58.6	8	22.8	3	**10.8**
1990	**28.8**	22	147.7	14	49.8	5	**16.0**
1972	**28.8**	13	67.8	7	18.8	4	**2.8**
Average/Total	**28.9**	75	443.0	44	141.8	24	**51.0**
Five coldest SST	SST average (May-Nov)	NS	NSD	H	HD	MH	MHD
1975	**27.8**	17	81.4	9	25.9	4	**5.5**
1971	**27.9**	23	117.5	14	38.5	6	**11.8**
1988	**28.0**	14	70.2	6	15.6	1	**2.3**
1973	**28.0**	15	71.0	8	28.5	3	**7.3**
1981	**28.0**	15	66.0	8	15.4	1	**1.0**
Average/Total	**27.9**	84	406.1	45	123.9	15	**27.775**
Student t-test p-value for difference between warmest and coldest years.	**2.8E-06**	0.24	0.35	0.46	0.32	0.07	**7.7E-02**

Bolded values are statistically significant ($p<0.05$)

the EDR does. Similar to results from the extreme year analysis, SSTs appear to be more strongly correlated with TC activity in the WDR. These results suggest that the small to negligible degrees of association between SSTs and measures of TC activity in the EDR would have been masked if the region had not been subdivided for analysis. The analysis was repeated using the Spearman rank coefficient correlation analysis to address the lack of normality in higher measures of hurricane activity especially in the WDR. The Spearman analysis showed the Pearson analysis to be robust.

Results from the bivariate analysis are similar to results from the extreme year analysis. Both suggest that SSTs in the EDR are not largely responsible for variations in TC activity. As discussed previously, these differences may be the result of the longitudinal stratification of SSTs or the presence of pre-existing SSTs necessary for hurricane formation during all years of analysis in the EDR. These results are consistent with Collins and Mason (2000), who also identified significant differences in storm activity (excluding major hurricane activity) for extreme temperature years to the west of 116°W.

Average seasonal SSTs from 1971–2002 for both the WDR and EDR reveal significant differences between the two regions. Average seasonal SST values for the 32 years of data were found to be 26.2°C (WDR) and 28.4°C (EDR). This is a substantial difference (2.2°C) to the east and west of 112°W longitude. The time series of annual SST for the WDR (Fig. 3) indicates that in only nine out of the 32 years analyzed did SSTs reach an average seasonal temperature

Table 4 Extreme year analysis results for SSTs in the WDR between 1971 and 2002

Five warmest SST	SST average (May-Nov)	NS	NSD	H	HD	MH	MHD
1992	**27.0**	**4**	**21.5**	**2**	**5.3**	**1**	**2.0**
1997	**27.0**	**5**	**19.8**	**1**	**2.3**	**1**	**2.0**
1994	**26.9**	**10**	**70.0**	**4**	**12.0**	**2**	**7.3**
1986	**26.7**	**8**	**30.3**	**2**	**7.0**	**1**	**2.3**
1993	**26.7**	**5**	**27.8**	**3**	**9.5**	**2**	**4.5**
Average/Total	**26.9**	**32**	**169.3**	**12**	**36.0**	**7**	**18.0**
Five coldest SST	SST average (May-Nov)	NS	NSD	H	HD	MH	MHD
1975	**25.1**	**3**	**7.0**	**0**	**0.0**	**0**	**0.0**
1971	**25.5**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
1974	**25.5**	**5**	**28.8**	**3**	**6.5**	**1**	**7.5**
1999	**25.6**	**3**	**17.0**	**1**	**4.3**	**0**	**0.0**
1973	**25.7**	**1**	**4.5**	**0**	**0.0**	**0**	**0.0**
Average/Total	**25.5**	**12**	**57.25**	**4**	**10.8**	**1**	**7.5**
Student's t-test p-value for difference between warmest and coldest years.	**6.9E-06**	**0.01**	**0.03**	**0.04**	**0.02**	**0.00**	**1.4E-01**

Bolded values are statistically significant ($p<0.05$)

Table 5 Results of the bivariate correlation analysis for all measures of TC activity and SSTs for all development regions (N=224, 1971–2002)

Variables (X, Y)	Pearson correlation coefficient (r)	Coefficient of determination (r^2)
NS & MDR SSTs	0.48	0.23
NSD & MDR SSTs	0.50	0.25
H & MDR SSTs	0.46	0.21
HD & MDR SSTs	0.43	0.18
MH & MDR SSTs	0.40	0.16
MHD & MDR SSTs	0.40	0.16
NS & EDR SSTs	0.19	0.03
NSD & EDR SSTs	0.25	0.06
H & EDR SSTs	0.19	0.04
HD & EDR SSTs	0.21	0.05
MH & EDR SSTs	0.23	0.05
MHD & EDR SSTs	0.27	0.07
NS & WDR SSTs	0.41	0.17
NSD & WDR SSTs	0.35	0.12
H & WDR SSTs	0.30	0.09
HD & WDR SSTs	0.25	0.06
MH & WDR SSTs	0.24	0.06
MHD & WDR SSTs	0.18	0.03

above 26.5°C. However, a total of 18 years were within± 0.5°C of the threshold value. Therefore, a change of only ±0.5°C in the average seasonal SST of the WDR could push average seasonal SSTs above the threshold value needed to create favourable conditions for hurricane formation, or below the threshold value precluding hurricane formation. As mentioned previously, the average seasonal SST value of 28.4°C for the EDR clearly indicates that SST conditions for hurricane formation already pre-exist in this region. The time series for the EDR (Fig. 3) indicates that even a drop of 1°C would still result in values high enough for hurricane formation. Therefore, it is more likely that other environmental factors are responsible for characterizing hurricane activity in the EDR; this is reflected in the weaker correlations identified between SSTs and TC activity measures in this region. Stronger correlations found in the WDR suggest that SSTs may be more of a limiting factor for hurricane formation in the region.

Another important aspect of these results is revealed when looking at frequency and duration parameters. The correlations identified within the WDR, although somewhat weaker than those identified for the entire main development region (MDR), follow the same general decrease in strength of association with SST from NS/NSD to H/HD. Correlations in the EDR do not exhibit this pattern. The strength of the association between SSTs and measures of NSD, MH, and MHD in the EDR are greater than the strength of association with NS, H and HD. Therefore, the SST gradient between the eastern and western sub-regions may also be related to the difference in the strengths of the correlations identified *within* each region. As mentioned previously, the strength of the correlations between SSTs and measures of TC activity decrease among the intensity parameters of NS to H to MH as well as among the duration parameters of NSD to HD to MHD. Stronger correlations for NS/NSD and H/HD are most likely due to the fact that in a region of SSTs that are normally less than sufficient for hurricane formation, the presence of warmer temperatures are associated with more storm activity on the whole. When observing the annual seasonal averages of SSTs in the WDR, it is fair to assume that low correlations with measures of MH activity and duration are a result of the fact that even when SSTs are higher, most of the time they are still not high enough to strengthen storm systems and enable hurricanes to intensify. In the EDR, the opposite trend is observed. Stronger correlations are evident for the intensity/duration parameters of MH/MHD and decrease with decreasing storm intensity with the exception of NSD. Since SSTs are already favorable for storm activity and any small increase or decrease in temperatures will not likely affect storm formation, it is reasonable that higher SSTs would not be associated with more NS or H. However, higher SSTs can allow existing storms to intensify into MH as they provide extra energy for intensification. This may explain why the strongest correlations with SSTs in the EDR are found with measures of MH/MHD. The measure of NSD is the one exception. Since NSD includes a total count of all storm days of varying intensity, this correlation might suggest that warmer SSTs overall have allowed storms to maintain their organization for more substantial lengths of time in the EDR. In fact, all measures of duration in the EDR show a greater degree of association between SSTs than do the measures of intensity. These relationships are not evident in the correlation results for SSTs and TC activity in the WDR. In fact, the opposite is evident. All measures of intensity in the WDR show stronger correlations with SSTs than do measures of duration.

4 Conclusions

In this paper we examined the influence of sea-surface temperatures in the main development region of the Eastern North Pacific Ocean, on six measures of tropical cyclone activity. Three approaches were taken. All results confirm that in order to understand the climatological factors affecting TC activity in the ENP, the main development region must be divided into two sub-regions of development. The division identifies a warmer and more active region to the east of 112°W (EDR) and a cooler and less active region to the west (WDR). This is a key result of this work. SSTs in the range of the formation threshold in the

WDR enhance the sensitivity of TC activity to SSTs. This may provide an explanation of why the main development region in the North Atlantic, similar to the WDR, is particularly sensitive to SST change (Steenhof and Gough 2008). This is one of the coolest development regions for hurricanes in the world. It may also explain why other hurricane regions, similar to the EDR, appear not to have responded as dramatically to SST variation.

The first approach, a trend analysis, found a significant trend of increasing SSTs in the data set spanning 1971 to 2002 for the EDR. Weak autocorrelation of the WDR SSTs prevented the identification of a significant trend. However, during the study period the rate of increase of SSTs in the WDR (0.03°C/year) has been slightly greater than the increase in the EDR (0.02°C/year). No significant temporal trends for any measure of TC activity in either development region were identified for the same period. Unfortunately, the lack of a long and reliable record of TC observations in the ENP makes these results questionable. As SSTs were only analyzed for the time period spanning from 1971 and 2002, there is also uncertainty as to whether these trends represent long-term changes or shorter-term (on the scale of tens of years) variability.

The second approach was an examination of the five warmest and five coolest seasons between 1971 and 2002. In the EDR, significant differences in numbers of MH and MHD activity were identified between groups of extreme SST years. However, in the WDR a significant increase in all measures of TC activity are noted when SSTs were extremely warm.

Bivariate correlation analysis identified highly significant correlations between all measures of TC activity and SSTs in both sub-regions of development. In the WDR, stronger correlations were found with intensity measures whereas in the EDR stronger correlations were found with duration measures. Even though all correlations with SSTs were found to be significant, low r^2 values indicate that there must be other variables contributing to the changes in TC activity. Therefore, it can be concluded that SSTs play a significant role in both TC formation and intensity in the ENP, yet there are clearly other factors involved.

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