5A.6 THE EFFECTS OF EARLY SEASON ENSO ON PEAK SEASON TROPICAL CYCLONES IN THE NORTHERN HEMISPHERE

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1. INTRODUCTION

The El Niño–Southern Oscillation (ENSO) has been shown in previous research to have a relationship to the mean formation region, intensity, and the number of tropical cyclones in the western North Pacific (WNP). Wang and Chan (2002) concluded that tropical storm life span increases and the formation shifts south and east in strong warm years. ENSO has been shown in many studies to have a connection to eastern North Pacific (ENP) tropical cyclone (TC) activity (Whitney and Hobgood 1997) and North Atlantic TC activity (Gray 1984a, 1984b) including U.S. regional activity (Tartaglione et. al. 2003, Smith et. al. 2007).

This study focuses on the relationship between the Sea Surface Temperature anomaly (SSTA) averaged over May, June and July on tropical cyclones forming up to three months later in the Northern Hemisphere peak season (August, September and October). The values studied include the number of cyclones, formation location, maximum wind intensity, and times required to reach different stages in their development.

2. METHODOLOGY

2.1 *Data*

Best track data of tropical cyclones for the 36 year period 1973–2008 are obtained online at the Joint Typhoon Warning Center web site for the WNP (www.npmoc.navy.mil/jtwc.html) and at the National Hurricane Center web site for the ENP and North Atlantic (http://www.nhc.noaa.gov/pastall.shtml). This time period is used to minimize the impact of decadal trends on tropical cyclone formation as well as to take into account improvements in satellite imagery and analysis (Dvorak 1975, 1984). The initial cyclone development is defined as a tropical depression (TD) with a minimum of 25 knot (13 m s^{-1}) average wind forming from 01 August through 31 October. Positions and times of tropical lows or disturbances before TD threshold are ignored. The times required for cyclones to reach tropical storm (TS) intensity and maximum wind speed, as well as the total life span, are calculated from this initial point. Cyclones that were initially observed as TSs or typhoons are excluded from the study, as are cyclones that do not reach at least tropical storm status (winds 34 knots or 17 m s^{-1}). In short, cyclones used in the study must begin as TDs but must reach at least TS strength. This reduces the influence of weak and/or short-lived systems. Recurving systems are defined primarily as having a northerly to easterly direction as they become extratropical over open water, especially north of 30ºN.

The MJJ seasonal SSTA values for the Niño-3.4 region are extracted online from the Climate Prediction Center's Web site. The Niño-3.4 region was deemed suitable for the study based on its sensitivity to both El Niño and La Niña events (Hanley et. al. 2003). The value for the May, June, July (MJJ) SSTA average has a correlation coefficient of 0.82 with respect to the August, September, October (ASO) SSTA average due to the phase-locking properties of ENSO (Chan and Xu 2000). Thus, the MJJ SSTA values are correlated with the peak season (ASO) properties of Northern Hemisphere tropical cyclones.

SST Anomalies for ASO used in Figures 4, 5 and 6 are provided online by the NOAA/ESRL Physical Sciences Division, Boulder Colorado.

2.2 *Stratification of El Niño versus La Niña years*

The separation of the MJJ mean SSTA into five categories was performed using a similar methodology to Wang and Chan (2002). The categories are strong warm (SSTA > 0.9 standard deviation, or 0.9σ), moderate warm (0.3σ < SSTA ≤ 0.9σ), neutral (-0.3σ ≤ SSTA ≤ 0.3σ), moderate cold (-0.9σ ≤ SSTA < -0.3σ), and strong cold (SSTA < -0.9σ). The result places ENSO neutral years between SSTA differences of -0.1ºC and 0.1ºC, Strong El Niño years above 0.5ºC (Strong La Niña below -0.5ºC) and weak-to-moderate El Niño/La Niña years between those values. The results of the stratification are listed in Table 1 below.

Table 1. Stratification of years into five categories based on the standard deviation of the MJJ mean Niño-3.4 SSTA.

ENSO Stratification	SSTA Range	Years with MJJ SSTAs within this range								Mean SSTA
Strong La Niña	below -0.5°C	1973	1974	1975	1985	1988	1999			-0.90
La Niña	-0.5°C to -0.2°C	1976	1978	1981	1984	1989	2000	2008		-0.37
Neutral	-0.1°C to 0.1°C	1979	1986	1996	1998	2001	2003	2007		-0.01
El Niño	0.2°C to 0.5°C	1977	1980	1990	1994	1995	2004	2005	2006	0.34
Strong El Niño	above 0.5°C	1982	1983	1987	1991	1992	1993	1997	2002	0.86
							Standard Deviation:			0.61

3. ANALYSIS AND RESULTS

The data is organized by the five strata of ENSO SSTA differences. The number of valid tropical

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storms and typhoons that initially form as TDs between 01 August through 31 October for each group are divided by the number of years in that group to obtain the mean number of cyclones per year. From that number the percentage of TSs and typhoons that recurve are also averaged. The amount of hours between tropical depression formation and the system reaching TS strength, maximum wind intensity, and final observed time are averaged for each category. The mean latitude and longitude for the TD formation are calculated for each group as are the locations of the first time each system reaches TS and typhoon or hurricane strength (over 64 knots or 33 m s^{-1}). The resulting values for the neutral years are used as a basis of comparison for the variation of averages for the other four ENSO strata, and two-sample *t* tests are applies to determine if the difference is statistically significant.

In addition to the overall means based on the five strata, the same ASO TC values above are averaged for each individual year and the results are correlated with MJJ SSTA observed that year.

3.1 *Western North Pacific (WNP)*

The results of the MJJ SSTA stratification and WNP cyclone characteristics averaged over those years are summarized in Table 2. The MJJ SSTA does not have an impact on the overall number of tropical cyclones in the WNP. Although there are, on average, two fewer typhoons in Strong La Niña years than in Strong El Niño years, this is not a statistically significant variation from neutral years. La Niña and especially Strong La Niña years exhibit a pronounced decrease in mean maximum wind intensity. Years with lower SSTAs shorten the average life span of cyclones, but this difference is only statistically significant in La Niña years as opposed to Strong La Niña periods. Although the percentage of tropical storms and typhoons that recurve is relatively unchanged between ENSO neutral and warmer years, there is a notably lower percentage in Strong La Niña years. This is due to the formation location shifting northwest as well as stronger subtropical high pressure in these years (Wu et. al. 2004). MJJ SSTAs also have a strong relationship with the mean formation location not only of TDs, but also on the region where they first become TSs and typhoons. Supporting the existing literature indicating the tropical cyclone formation region shifts south and east during warm years, there is a mostly linear change in development latitude and longitude for TDs, TSs, and typhoons, especially in Strong El Niño years. This difference in formation location for TDs is depicted in Figure 1a. Figure 1b shows the average locations where systems first reach TS intensity and Figure 1c is similar to Figure 1b, but for typhoon intensity. Excepting the average formation location for neutral years, there is a linear trend from the coldest years (northwest) to the warmest years (southeast).

Table 2. For the western North Pacific, the mean SSTA and number of years in each MJJ strata, the mean maximum wind speed, and the mean number of hours required for systems to reach TS intensity, their maximum intensity, and the end of their life span. In separate sections of tropical depression, tropical storm, and typhoon results, Columns A and B are mean formation latitude and longitude, respectively. Column C is the raw number of TSs or typhoons with systems per year in parentheses and Column D is the number of TSs/typhoons recurving with percentage of total systems in parentheses. Numbers in bold orange indicate that the difference from neutral year averages is statistically significant at the 5% confidence level based on a two-sample *t* test. Numbers in bold red indicate a statistically significant variation at the 1% confidence level.

	Mean SSTA	Mean Maximum Wind		Mean Time (hours) from TD Genesis			Tropical Depressions	
	(Years)	Speed (m s^{-1})		To TS	To Max	Life Span	A	B
Strong La Niña	-0.90 (6)	**144.9 (75 kts)**		33.59	83.34	155.20	17.53	135.78
La Niña	-0.37 (7)	**146.6 (75 kts)**		27.06	80.69	**150.88**	16.31	139.60
Neutral	-0.01 (7)	171.2 (88 kts)		27.90	88.80	178.50	16.62	137.32
El Niño	0.34 (8)	169.6 (87 kts)		25.85	94.04	173.84	15.95	141.86
Strong El Niño	0.86 (8)	175.9 (90 kts)		30.32	98.39	211.66	**13.93**	**144.23**
	Tropical Storm Development Characteristics				Typhoon Development Characteristics			
	A	B	C	D	A	B	C	D
Strong La Niña	19.19	133.16	82 (13.7)	**26 (32%)**	20.23	131.74	49 (8.2)	**19 (39%)**
La Niña	18.17	137.26	96 (13.7)	41 (43%)	19.47	137.62	53 (7.6)	27 (51%)
Neutral	18.28	134.73	80 (11.4)	42 (52%)	20.01	134.55	57 (8.1)	34 (60%)
El Niño	17.38	138.93	110 (13.8)	53 (48%)	19.01	137.36	77 (9.6)	44 (57%)
Strong El Niño	**15.78**	**141.11**	113 (14.1)	53 (47%)	**17.20**	**139.38**	80 (10.0)	43 (54%)

3.2 *Eastern North Pacific (ENP)*

As in Table 2, ENP results are shown in Table 3. Although there was little difference in the number of tropical storms and hurricanes between most of the SSTA strata, there are on average 3 more tropical storms in Strong El Niño years, which is significantly more than all other periods. As in the WNP, El Niño and Strong El Niño years exhibit higher maximum wind intensity, but not substantially above average. Cyclones do take significantly more time in order to reach maximum intensity in Strong El Niño years. The average life span of cyclones is also higher in the two warmer strata. Few systems recurve, so no measurable link with ENSO was expected or observed. The latitude of TD, TS, and hurricane development is significantly farther south in Strong El Niño years. TSs develop farther west in (Strong) El Niño years, although this relationship is not discernible for TDs and hurricanes. As in Figures 1a through 1c, Figures 2a, 2b, and 2c show average locations for TD, TS, and hurricane formation and development in the ENP.

Table 3. For the eastern North Pacific, the mean SSTA and number of years in each MJJ strata, the mean maximum wind speed, and the mean number of hours required for systems to reach TS intensity, their maximum intensity, and the end of their life span. In separate sections of tropical depression, tropical storm, and hurricane results, Columns A and B are mean formation latitude and longitude, respectively. Column C is the raw number of TSs or hurricanes with systems per year in parentheses and Column D is the number of TSs/hurricanes recurving with percentage of total systems in parentheses. Numbers in bold orange indicate that the difference from neutral year averages is statistically significant at the 5% confidence level based on a two-sample *t* test. Numbers in bold red indicate a statistically significant variation at the 1% confidence level.

	Mean SSTA	Mean Maximum Wind		Mean Time (hours) from TD Genesis			Tropical Depressions	
	(Years)	Speed (m s $^{-1}$)		To TS	To Max	Life Span	A	B
Strong La Niña	-0.90 (6)	139.7 (72 kts)		23.22	71.22	159.26	13.73	-111.20
La Niña	-0.37 (7)	136.5 (70 kts)		22.29	70.95	155.43	14.31	-108.83
Neutral	-0.01 (7)	140.2 (72 kts)		17.11	63.33	143.67	14.21	-108.14
El Niño	0.34 (8)	149.3 (77 kts)		23.73	69.49	**179.46**	13.85	-112.35
Strong El Niño	0.86 (8)	158.3 (81 kts)		22.02	**80.93**	**180.48**	**12.50**	-112.81
	Tropical Storm Development Characteristics				Hurricane Development Characteristics			
	A	B	C	D	A	B	C	D
Strong La Niña	14.64	-114.27	46 (7.7)	1 (2%)	17.08	-118.14	31 (5.2)	1 (3%)
La Niña	15.15	-111.87	63 (9.0)	1 (2%)	16.60	-116.33	34 (4.9)	1 (3%)
Neutral	15.11	-110.53	54 (7.7)	0 (0%)	16.43	-112.76	33 (4.7)	0 (0%)
El Niño	14.69	**-115.45**	67 (8.4)	2 (3%)	16.23	-117.91	42 (5.2)	2 (5%)
Strong El Niño	**13.40**	**-115.51**	**88 (11.0)**	6 (7%)	**14.69**	-110.81	51 (6.4)	5 (10%)

3.3 *North Atlantic*

The North Atlantic results are listed in Table 4. As Gray (1984a) and subsequent research have shown, El Niño events coincide with inhibited tropical cyclone formation and intensification in the North Atlantic. As opposed to the ENP findings, there are on average two fewer tropical storms and hurricanes per year in Strong El Niño years. Only the number of hurricanes forming during Strong El Niño events is substantially lower from normal variability. The same period also exhibits decreased mean maximum wind speed. While Strong El Niño years evidence a lower average number of hours required for TDs to become TSs, the same is true of La Niña years. The mean life span of cyclones is shorter than neutral years in all four other strata, but this decrease is significant only during La Niña events. The effect of SSTA changes on the formation region is pronounced only in Strong El Niño years, wherein tropical depressions and tropical storms form several degrees farther north in than in neutral or La Niña years. In particular, the mean latitude for the point at which tropical storms become hurricanes is typically between 21ºN and 24ºN but in Strong El Niño years it shifts much farther north, to near 28ºN. As in Figures 1a-c, Figures 3a, 3b, and 3c show average locations for TD, TS, and hurricane formation and subsequent intensification, respectively, in the North Atlantic.

Table 4. As in Table 3 except for the North Atlantic.

	Mean SSTA	Mean Maximum Wind		Mean Time (hours) from TD Genesis			Tropical Depressions	
	(Years)	Speed (m s $^{-1}$)		To TS	To Max	Life Span	A	B
Strong La Niña	-0.90 (6)	155.7 (80 kts)		33.75	98.38	175.62	18.66	-60.64
La Niña	-0.37 (7)	139.4 (72 kts)		**21.39**	81.87	**164.42**	20.45	-59.72
Neutral	-0.01 (7)	160.0 (82 kts)		29.59	98.17	209.28	18.05	-56.82
El Niño	0.34 (8)	152.6 (79 kts)		24.85	87.80	193.10	18.42	-55.78
Strong El Niño	0.86 (8)	**135.4 (70 kts)**		**21.13**	82.57	167.74	**21.53**	-60.61
	Tropical Storm Development Characteristics				Hurricane Development Characteristics			
	A	B	C	D	A	B	C	D
Strong La Niña	20.97	-65.07	48 (8.0)	26 (54%)	21.30	-68.46	28 (4.7)	18 (64%)
La Niña	21.83	-61.70	62 (8.9)	38 (61%)	23.79	-63.48	33 (4.7)	26 (79%)
Neutral	19.16	-61.28	58 (8.3)	31 (53%)	21.35	-59.68	37 (5.3)	27 (73%)
El Niño	20.10	-59.20	71 (8.9)	39 (55%)	23.20	-61.07	47 (5.9)	33 (70%)
Strong El Niño	**23.18**	-62.96	46 (5.8)	26 (57%)	**27.99**	-67.63	**22 (2.8)**	17 (77%)

3.4 *Yearly correlation*

Table 5 shows the yearly SSTA averages for MJJ and ASO, with the correlation values between the two. When the same SSTA stratification applied to the MJJ SSTAs is applied to the ASO SSTAs, there are a few years that significantly change strata. 1976, 1986, 1992, 1995, 1998, and 2007 change by two strata and the biggest difference is 1983, which moves from the Strong El Niño category in MJJ to the La Niña category in ASO. Even so, there is a correlation between the MJJ and ASO SSTAs which is statistically significant at the 1% confidence level. Tables 6, 7, and 8 correlate TC values for each basin with the MJJ SSTA values.

Table 5. SSTA values in MJJ and ASO listed for each year. The Pearson's product-moment coefficient and the Spearman's rank correlation coefficient between both columns are statistically significant at a 1% confidence level.

Year	SSTA in MJJ	SSTA in ASO
1973	-0.9	-1.4
1974	-0.8	-0.5
1975	-1.1	-1.5
1976	-0.2	0.5
1977	0.4	0.5
1978	-0.4	-0.4
1979	-0.1	0.3
1980	0.3	-0.1
1981	-0.3	-0.3
1982	0.7	1.5
1983	0.6	-0.6
1984	-0.4	-0.3
1985	-0.6	-0.5
1986	0	0.7
1987	1.2	1.6
1988	-1.2	-1.3
1989	-0.4	-0.3
1990	0.2	0.3
1991	0.8	0.9
1992	0.8	0
1993	0.7	0.4
1994	0.5	0.7
1995	0.2	-0.5
1996	-0.1	-0.1
1997	1.3	2.2
1998	0	-1
1999	-0.8	-1
2000	-0.5	-0.4
2001	0.1	0.1
2002	0.8	1.1
2003	0.1	0.6
2004	0.5	0.9
2005	0.4	0.2
2006	0.2	0.6
2007	-0.1	-0.7
2008	-0.4	0
Standard Deviation		0.74
Covariance		0.42
Pearson's Correlation		**0.82**
Spearman's Rank Correlation		**0.75**

Table 6 shows the yearly correlations between the MJJ SSTA and WNP mean maximum wind speed, the time elapsed between TD formation and intensification to TS strength, reaching maximum intensity, and the final observation time, the mean latitudes and longitudes for formation and development, and TS/typhoon numbers for each year. The correlation between MMJ SSTAs and both latitude and longitude of TD, TS, and typhoon development is statistically significant, providing additional support to the shift of development south and east in warmer years. The positive correlation between SSTA and mean maximum wind speed is also strong, indicating a close relationship between Niño-3.4 SSTAs and peak storm intensity. The number of TDs and TSs show little correlation to the MJJ SSTAs, but the Spearman's Rank Correlation Coefficient between the SSTAs and the number of typhoons meets the 5% confidence level. This is also true of the time required to reach maximum intensity. Figure 4 depicts the formation locations for TDs in the seven warmest, neutral and coldest years plotted over the average SSTA in ASO for those years.

Table 7 depicts yearly correlations for the ENP similar to Table 6. The mean latitude of TC formation and development correlate significantly to the MJJ SSTAs, especially for hurricanes. There is a notable correlation between MJJ SSTAs and the average maximum wind speed and, to a lesser degree, with the number of TSs. Figure 5 depicts the formation locations for TDs in the seven warmest, neutral and coldest years overlaid on the average SSTA in ASO.

Table 8 is similar to Table 7, but for the North Atlantic. In these results, the only correlation that meets the 5% confidence level is between the MJJ SSTA values and the time required for a TD to intensify to a TS. This negative correlation indicates TDs reach TS strength earlier during El Niño events. Figure 6 is similar to Figure 5 except for the North Atlantic.

4. CONCLUSIONS

An evaluation of the Niño-3.4 region Sea Surface Temperature anomaly during the May-June-July season can provide valuable clues to the characteristics of Northern Hemisphere tropical cyclones forming during the peak formation months (01 August through 31 October). Of the five ENSO strata defined, the most significant variation of tropical cyclone characteristics occurs during Strong El Niño years. As in Carmago et. al (2007), compared to other ocean basins the strongest relationship between El Niño and TC development is observed in the WNP, but this study adds there is a strong correlation between higher SSTAs earlier in the year (MJJ) and development of tropical depressions, tropical storms and typhoons farther south and east during the peak season (ASO). Negative MJJ SSTAs correspond with less intense cyclones in general and, to a lesser degree, shorter life spans. These results can be attributed to the fact that cyclones form farther north and west, in colder waters, during La Niña periods. One feature in particular that varies in Strong La Niña years is the number of recurving WNP TSs and typhoons.

Tropical depressions also tend to form farther south in the eastern North Pacific during warmer years. The higher sea surface temperatures in this formation region may contribute to longer life spans and a higher number of TSs during Strong El Niño years. Although Strong El Niño years as a category do not exhibit a significantly higher maximum wind speed, there is a relatively strong correlation between the two values on a year-to-year basis.

In the North Atlantic, the MJJ SSTAs in a given year are not as influential as whether or not that year can be classified as a Strong El Niño. In Strong El Niño years, tropical storms and especially hurricanes are less likely to form and do not reach the same average maximum wind intensity as in all other years. This likely results from a significant northward shift in development for all cyclones during Strong El Niño events, placing TDs, TSs, and hurricanes in colder waters.

The relationship between ENSO and other synoptic features such as vertical wind shear, convergence and divergence are still being investigated. Further research on the signal between early-to-mid year SSTAs on prevailing conditions during the peak season may shed light on how ENSO and related environmental features increase or inhibit Northern Hemisphere tropical cyclone development. Additional study using this methodology can be applied to all systems, including those that do not intensify to TS strength, for all basins. Another area of investigation is the effect of ENSO on Southern Pacific tropical cyclones. A demonstrable link between SSTAs and TC tendencies suggests further study into predicting SSTA trends in the preceding months is warranted.

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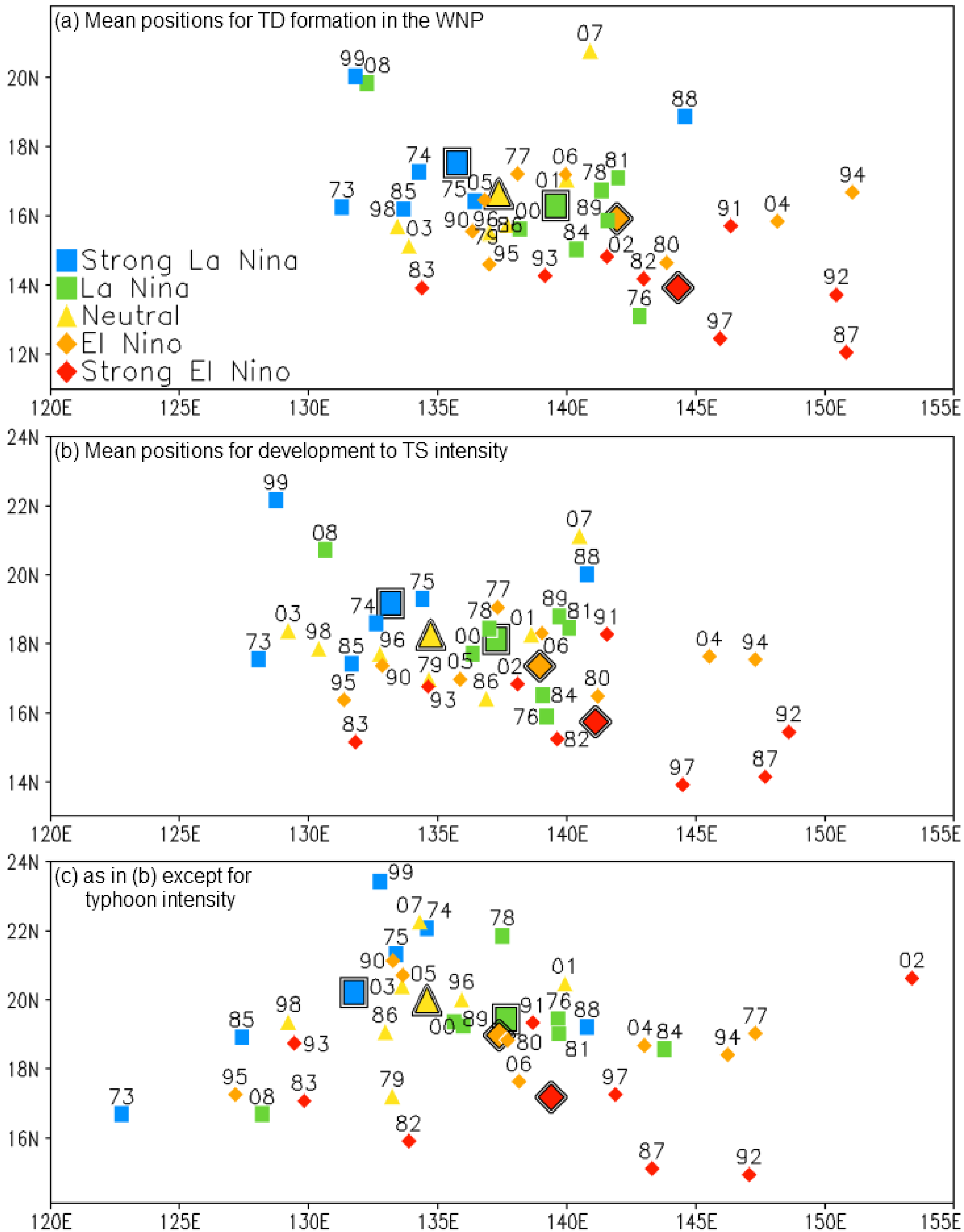

Fig. 1. (a) The mean positions for western North Pacific tropical depression formation. (b) as in (a) except for initial point of development to tropical storm intensity. (c) as in (a) except for development to typhoon intensity. The average position for each year is marked by a symbol depending on with of the five ENSO strata includes that year. The mean position for each of the five ENSO strata is noted by a larger symbol framed in two black lines.

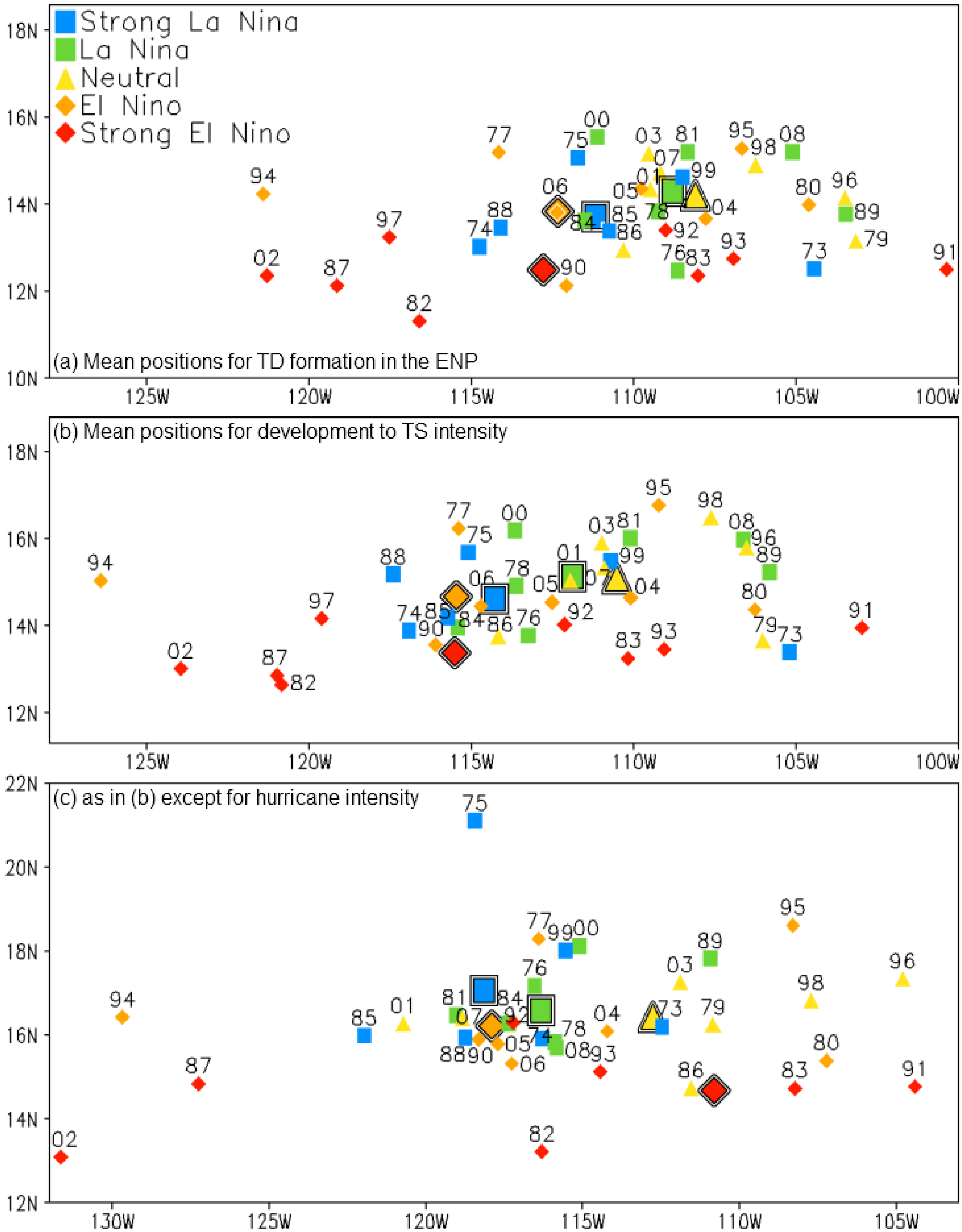

Fig. 2. (a) The mean positions for eastern North Pacific tropical depression formation. (b) as in (a) except for initial point of development to tropical storm intensity. (c) as in (a) except for development to hurricane intensity. The average position for each year is marked by a symbol depending on with of the five ENSO strata includes that year. The mean position for each of the five ENSO strata is noted by a larger symbol framed in two black lines.

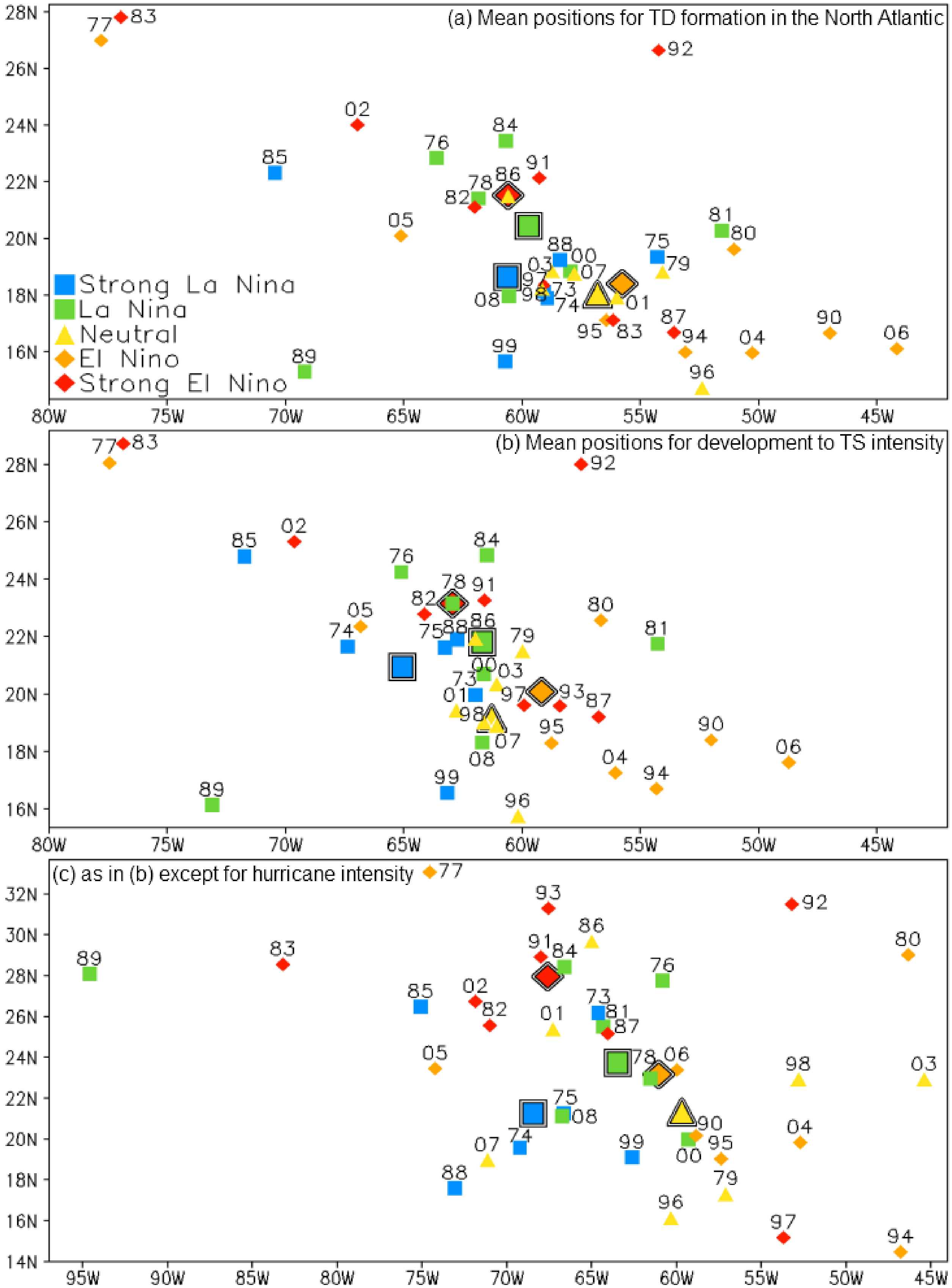

Fig. 3. As in Fig. 2 except for the North Atlantic.

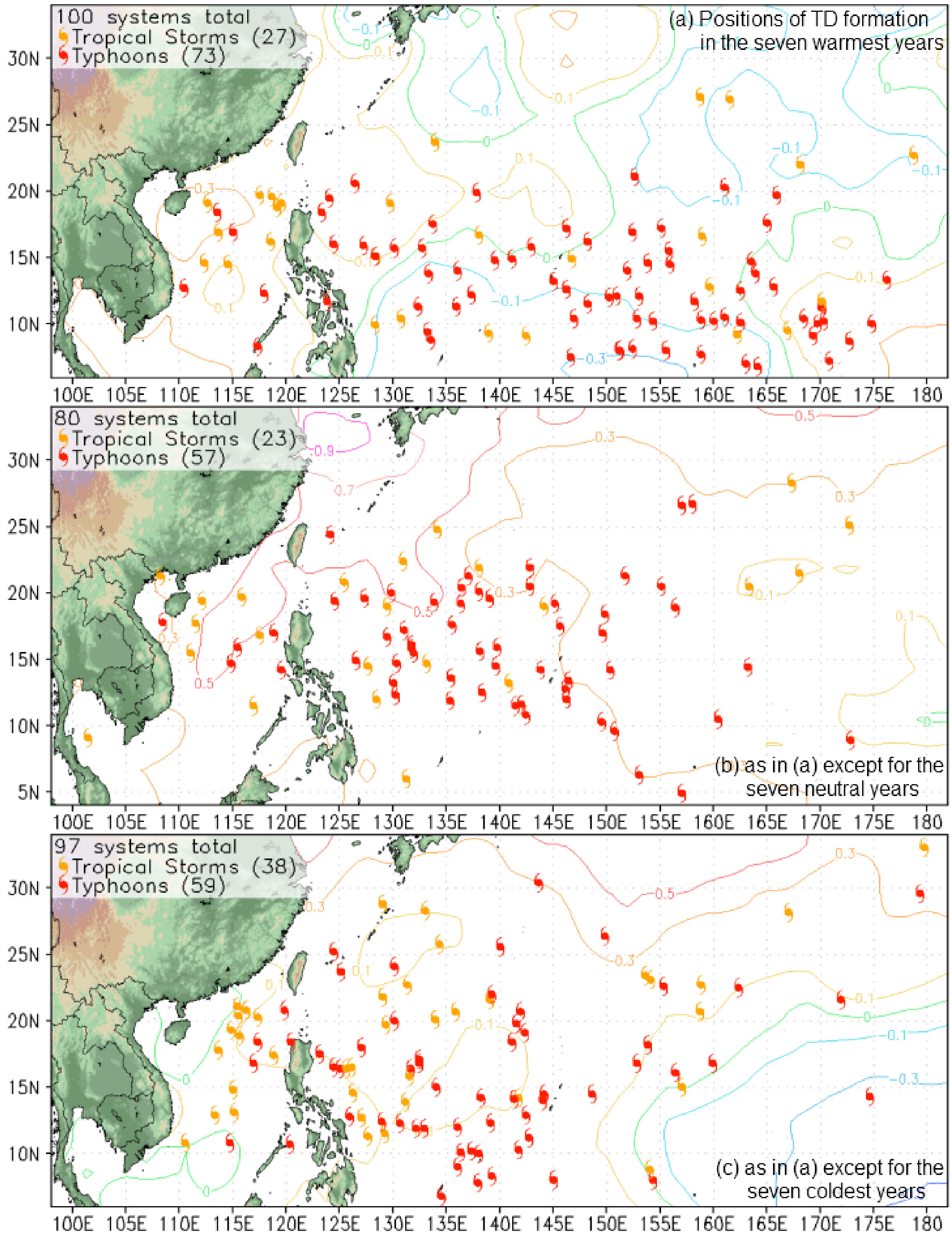

Fig. 4. The initial position for tropical depression formation during the seven (a) warmest, (b) neutral, and (c) coldest years in the western North Pacific. Cyclones that reached tropical storm strength are labeled in orange, and those that became typhoons are marked in red. These positions are overlaid on the Sea Surface Temperature anomaly for August, September and October averaged over the seven years in each panel.

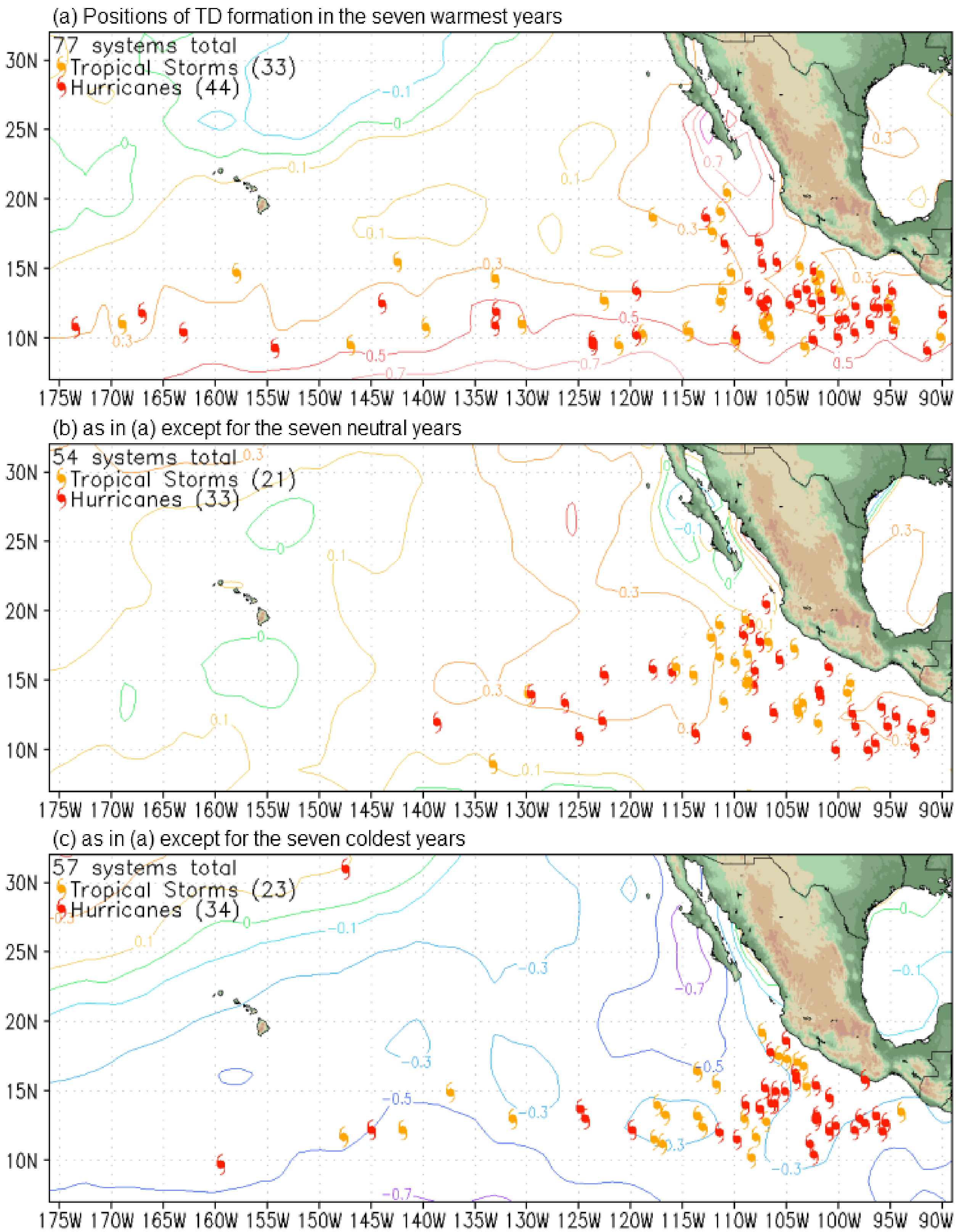

Fig. 5. The initial position for tropical depression formation during the seven (a) warmest, (b) neutral, and (c) coldest years in the eastern North Pacific. Cyclones that reached tropical storm strength are labeled in orange, and those that became hurricanes are marked in red. These positions are overlaid on the Sea Surface Temperature anomaly for August, September and October averaged over the seven years in each panel.

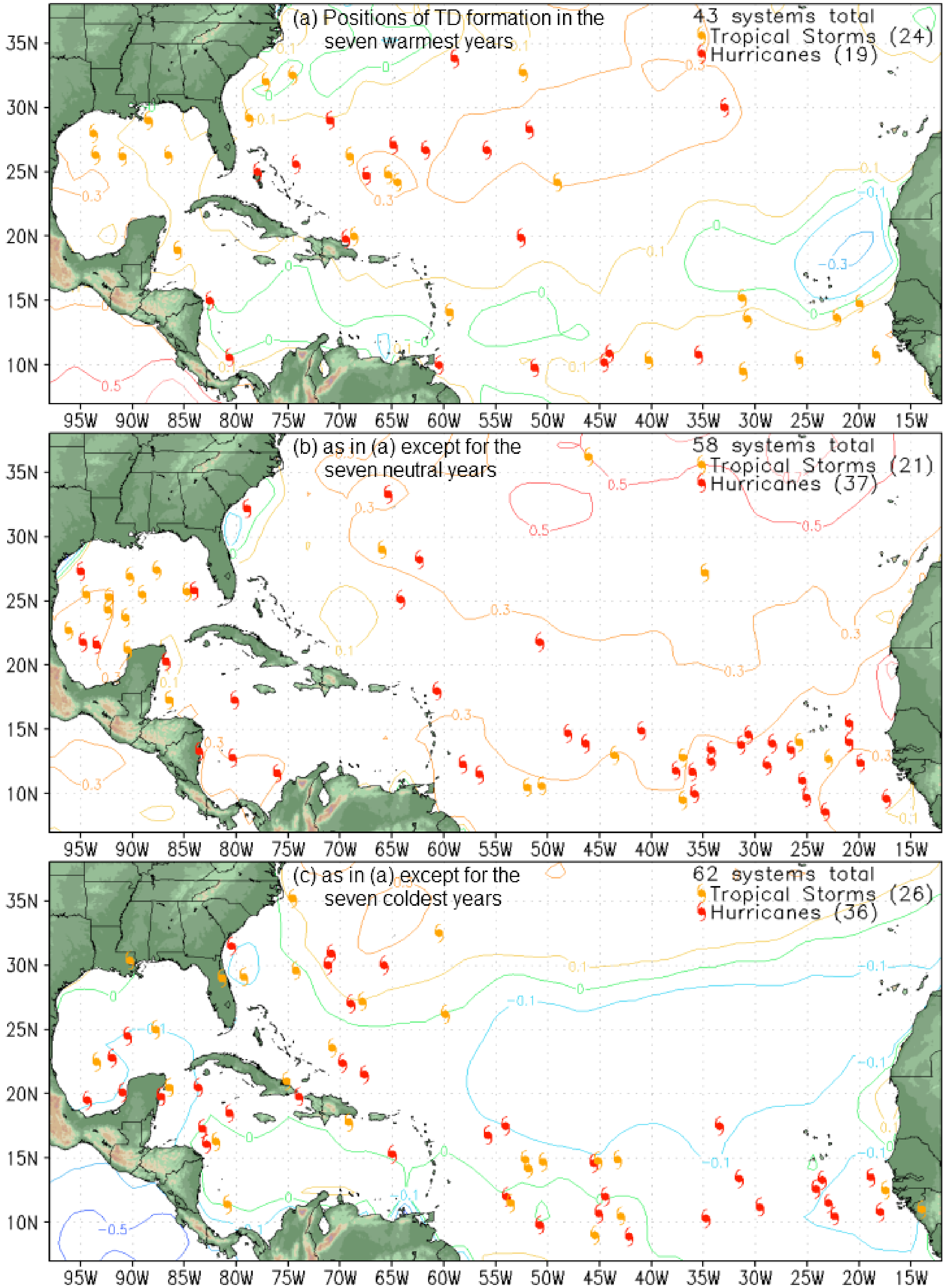

Fig. 6. As in Fig. 5 except for the North Atlantic.

Table 6. For the western North Pacific, the mean maximum wind speed, and the mean number of hours required for TDs to reach TS strength, their maximum intensity, and their final observed position (total life span) for each year. In separate sections of tropical depression, tropical storm and typhoon results, Columns A and B are mean formation latitude and longitude, respectively. For TSs and typhoons, Column C is the number observed each year and Column D is the percentage of those systems that recurve. Numbers in bold orange indicate that the correlation between that value and the MJJ SSTA for that year is statistically significant at the 5% confidence level. Numbers in bold red indicate a statistically significant correlation at the 1% confidence level.

	Wind Max	Mean time from TD		Mean Life	TDs		Tropical Storms				Typhoons			
					Location		Location		Number		Location		Number	
Year	($m\ s^{-1}$)	to TS	to Max	Span	A	B	A	B	C	D	A	B	C	D
1973	163.5	26.73	81.82	176.18	16.26	131.26	17.57	128.04	11	9%	16.70	122.73	8	12%
1974	134.1	27.60	86.40	176.00	17.27	134.25	18.61	132.60	15	33%	22.08	134.57	9	56%
1975	154.8	39.00	90.86	170.57	16.44	136.43	19.31	134.39	14	50%	21.34	133.37	10	50%
1976	142.6	40.67	84.67	211.33	13.12	142.80	15.91	139.21	9	56%	19.46	139.68	5	80%
1977	129.6	18.67	68.67	120.00	17.23	138.07	19.08	137.32	9	33%	19.05	147.28	4	50%
1978	140.1	33.18	95.65	155.29	16.74	141.33	18.46	136.99	17	28%	21.87	137.49	10	40%
1979	170.5	28.36	87.27	184.91	15.51	137.02	16.98	134.65	11	64%	17.21	133.21	7	71%
1980	169.3	22.00	91.00	152.00	14.67	143.86	16.51	141.18	12	50%	18.86	137.70	9	56%
1981	148.4	20.18	73.09	124.91	17.11	141.97	18.48	140.08	11	36%	19.06	139.68	5	60%
1982	191.4	19.85	91.38	208.15	14.20	142.97	15.27	139.62	13	62%	15.93	133.86	11	64%
1983	158.5	17.08	70.15	137.54	13.94	134.38	15.18	131.80	13	23%	17.09	129.81	7	43%
1984	148.8	18.75	72.75	134.25	15.04	140.36	16.52	139.06	16	44%	18.59	143.77	9	44%
1985	153.4	20.57	83.14	138.86	16.20	133.67	17.44	131.65	14	28%	18.93	127.40	9	22%
1986	176.9	13.20	166.80	252.00	15.74	137.68	16.42	136.86	5	40%	19.07	132.95	4	50%
1987	201.7	35.00	119.50	242.50	12.07	150.82	14.17	147.68	12	33%	15.13	143.29	10	40%
1988	140.3	52.50	91.12	146.25	18.88	144.57	20.03	140.78	16	31%	19.23	140.77	7	56%
1989	155.5	39.43	104.14	173.57	15.87	141.57	18.81	139.69	14	50%	19.26	135.97	10	50%
1990	147.7	36.80	96.00	170.40	15.58	136.33	17.39	132.83	15	47%	21.15	133.25	11	64%
1991	173.8	39.38	110.25	212.62	15.73	146.33	18.29	141.55	16	50%	19.35	138.68	11	45%
1992	172.8	30.67	115.33	234.67	13.74	150.44	15.47	148.60	18	56%	14.96	147.06	12	57%
1993	158.8	34.00	92.40	168.00	14.29	139.15	16.78	134.61	15	47%	18.77	129.44	11	45%
1994	173.4	38.53	121.58	237.16	16.70	151.06	17.56	147.29	19	53%	18.43	146.22	13	69%
1995	175.5	32.33	100.33	180.00	14.62	136.98	16.39	131.34	18	39%	17.27	127.14	13	38%
1996	154.4	32.33	76.33	201.33	15.55	136.98	17.71	132.74	18	44%	20.03	135.91	11	64%
1997	195.0	33.20	102.40	224.40	12.47	145.93	13.93	144.46	15	53%	17.27	141.86	12	57%
1998	189.5	30.60	97.80	186.60	15.70	133.43	17.87	130.38	10	50%	19.36	129.20	8	50%
1999	125.5	31.00	62.00	123.00	20.05	131.79	22.18	128.73	12	33%	23.43	132.75	6	33%
2000	163.3	26.40	90.80	165.20	15.63	138.17	17.73	136.34	15	40%	19.37	135.61	10	50%
2001	173.5	26.77	95.08	175.38	17.05	139.96	18.28	138.61	13	62%	20.48	139.91	10	70%
2002	155.5	30.55	74.73	272.91	14.84	141.55	16.85	138.09	11	45%	20.65	153.37	6	83%
2003	185.7	46.80	100.80	171.60	15.14	133.87	18.39	129.19	10	40%	20.41	133.60	8	50%
2004	177.7	22.29	88.71	169.29	15.86	148.15	17.66	145.51	14	71%	18.70	143.00	10	80%
2005	195.2	10.50	86.50	151.00	16.47	136.80	17.00	135.87	12	42%	20.73	133.64	11	45%
2006	177.6	9.82	72.55	157.64	17.22	139.93	18.33	139.03	11	45%	17.65	138.13	6	50%
2007	165.2	11.54	54.92	115.38	20.78	140.90	21.13	140.48	13	62%	22.27	134.29	9	56%
2008	126.4	14.14	40.71	108.00	19.85	132.24	20.73	130.63	14	50%	16.70	128.18	4	50%
Standard Dev.	19.77	10.22	21.30	40.21	1.90	5.32	1.76	5.38	2.95	0.13	1.95	6.47	2.52	0.15
Covariance	7.44	-0.63	3.82	12.48	-0.70	1.77	-0.71	1.69	0.03	0.03	-0.53	1.61	0.50	0.03
Correlation	**0.61**	-0.10	0.29	**0.51**	**-0.60**	**0.54**	**-0.65**	**0.51**	0.02	**0.35**	**-0.45**	**0.41**	0.32	0.30
Spearman's	**0.61**	-0.02	**0.37**	**0.44**	**-0.57**	**0.50**	**-0.61**	**0.46**	0.01	**0.35**	**-0.39**	**0.37**	**0.39**	0.23

Table 7. For the eastern North Pacific, the mean maximum wind speed, and the mean number of hours required for TDs to reach TS strength, their maximum intensity, and their final observed position (total life span) for each year. In separate sections of tropical depression, tropical storm and hurricane results, Columns A and B are mean formation latitude and longitude, respectively. For TSs and hurricanes, Column C is the number observed each year and Column D is the percentage of those systems that recurve. Numbers in bold orange indicate that the correlation between that value and the MJJ SSTA for that year is statistically significant at the 5% confidence level. Numbers in bold red indicate a statistically significant correlation at the 1% confidence level.

	Wind Max	Mean time from TD		Mean Life	TDs		Tropical Storms				Hurricanes			
					Location		Location		Number		Location		Number	
Year	(m s $^{-1}$)	to TS	to Max	Span	A	B	A	B	C	D	A	B	C	D
1973	130.2	18.00	55.20	120.00	12.52	-104.46	13.40	-105.22	5	0%	16.20	-112.47	3	0%
1974	131.8	14.67	53.33	133.33	13.03	-114.77	13.89	-116.94	9	0%	15.92	-116.28	6	0%
1975	124.2	20.00	68.67	125.33	15.07	-111.74	15.69	-115.10	9	11%	21.12	-118.44	5	20%
1976	153.1	34.50	93.00	195.75	12.47	-108.67	13.78	-113.26	8	0%	17.18	-116.54	5	0%
1977	128.8	12.00	36.00	84.00	15.20	-114.17	16.25	-115.42	4	0%	18.30	-116.40	3	0%
1978	144.7	23.33	74.00	157.33	13.84	-109.27	14.92	-113.62	9	11%	15.84	-115.89	7	14%
1979	176.9	14.40	74.40	122.40	13.16	-103.18	13.66	-106.04	5	0%	16.25	-110.85	4	0%
1980	149.7	10.80	42.00	145.20	14.00	-104.64	14.38	-106.30	5	0%	15.40	-107.23	3	0%
1981	132.2	14.40	63.60	120.00	15.20	-108.36	16.02	-110.13	10	0%	16.47	-119.05	6	0%
1982	136.1	31.71	79.29	166.71	11.32	-116.62	12.65	-120.86	14	0%	13.23	-116.30	7	0%
1983	167.0	18.00	99.27	186.00	12.36	-108.03	13.26	-110.18	11	0%	14.74	-108.24	7	0%
1984	151.5	29.00	90.50	170.00	13.63	-111.53	13.96	-115.44	12	0%	16.27	-117.36	7	0%
1985	158.2	34.91	96.55	191.45	13.39	-110.78	14.19	-115.75	11	0%	15.99	-121.97	9	0%
1986	129.0	20.73	60.00	121.09	12.96	-110.35	13.75	-114.18	11	0%	14.74	-111.54	5	0%
1987	135.2	14.18	55.64	121.09	12.14	-119.15	12.87	-121.01	11	0%	14.85	-127.25	6	0%
1988	142.6	32.00	72.00	205.00	13.47	-114.12	15.18	-117.42	6	0%	15.95	-118.75	4	0%
1989	155.5	22.80	80.40	166.80	13.78	-103.50	15.24	-105.84	5	0%	17.83	-110.93	3	0%
1990	163.6	28.50	88.00	211.00	12.14	-112.10	13.57	-116.11	12	0%	15.90	-118.32	9	0%
1991	165.2	21.43	72.86	225.43	12.51	-100.40	13.96	-103.00	7	0%	14.78	-104.40	5	0%
1992	151.0	18.00	92.00	175.60	13.41	-109.03	14.03	-112.14	15	13%	16.31	-117.21	9	22%
1993	190.5	21.60	83.40	214.20	12.75	-106.94	13.47	-109.09	10	0%	15.13	-114.44	7	0%
1994	141.3	40.62	94.62	188.77	14.25	-121.42	15.05	-126.43	13	8%	16.44	-129.67	7	14%
1995	165.2	30.00	75.00	172.50	15.30	-106.70	16.77	-109.25	4	0%	18.63	-108.30	3	0%
1996	136.1	25.50	60.00	165.00	14.15	-103.52	15.80	-106.55	4	0%	17.35	-104.80	2	0%
1997	170.1	28.80	74.40	189.00	13.25	-117.54	14.17	-119.62	10	30%	14.48	-55.92	5	40%
1998	151.9	19.50	69.75	149.25	14.90	-106.26	16.49	-107.65	8	0%	16.83	-107.72	6	0%
1999	145.8	15.00	68.00	177.00	14.63	-108.52	15.48	-110.72	6	0%	18.02	-115.55	4	0%
2000	106.0	20.18	51.27	113.45	15.55	-111.15	16.19	-113.68	11	0%	18.13	-115.10	3	0%
2001	139.0	12.00	66.00	132.60	14.35	-109.50	15.04	-111.95	10	0%	16.28	-120.72	6	0%
2002	167.2	21.60	84.00	192.60	12.37	-121.31	13.02	-123.96	10	10%	13.10	-131.64	5	20%
2003	131.2	13.80	47.40	157.20	15.16	-109.56	15.91	-111.00	10	0%	17.26	-111.90	7	0%
2004	143.4	14.25	59.25	168.00	13.68	-107.81	14.65	-110.11	8	0%	16.10	-114.22	4	0%
2005	140.9	18.00	61.80	189.60	14.37	-109.79	14.55	-112.53	10	0%	15.80	-117.70	6	0%
2006	156.4	18.55	56.73	186.00	13.83	-112.43	14.45	-114.69	11	9%	15.33	-117.26	7	14%
2007	134.5	18.00	76.00	177.00	14.72	-109.20	15.35	-110.92	6	0%	16.40	-118.83	3	0%
2008	123.9	11.25	46.50	186.00	15.21	-105.12	15.99	-106.64	8	0%	15.70	-115.83	3	0%
Standard Dev.	17.09	7.47	16.07	32.93	1.09	4.93	1.10	5.34	2.88	0.06	1.50	11.50	1.88	0.09
Covariance	4.40	-0.07	1.32	4.64	-0.24	-0.78	-0.26	-0.73	0.60	0.01	-0.51	1.76	0.29	0.02
Correlation	**0.42**	-0.02	0.13	0.23	**-0.35**	-0.26	**-0.38**	-0.22	**0.34**	0.32	**-0.55**	0.25	0.25	0.31
Spearman's	**0.40**	-0.05	0.18	0.27	**-0.35**	-0.16	**-0.37**	-0.14	0.32	0.23	**-0.50**	0.10	0.28	0.25

Table 8. As in Table 7 except for the North Atlantic.

	Wind Max	Mean time from TD		Mean Life	TDs		Tropical Storms				Hurricanes			
					Location		Location		Number		Location		Number	
Year	(m s $^{-1}$)	to TS	to Max	Span	A	B	A	B	C	D	A	B	C	D
1973	139.3	32.00	102.00	184.00	18.13	-59.07	19.98	-61.98	6	50%	26.20	-64.63	3	67%
1974	144.6	46.50	73.50	157.50	17.90	-58.94	21.66	-67.39	8	50%	19.58	-69.25	4	25%
1975	180.8	61.20	180.00	217.20	19.36	-54.30	21.62	-63.26	5	80%	21.27	-66.65	4	75%
1976	149.5	16.50	81.00	165.00	22.85	-63.62	24.26	-65.11	8	62%	27.77	-60.85	6	83%
1977	153.9	17.00	49.00	92.00	27.00	-77.80	28.08	-77.43	6	50%	33.08	-74.54	5	60%
1978	138.0	27.60	87.00	136.80	21.42	-61.85	23.16	-62.96	10	50%	22.98	-61.56	5	60%
1979	170.1	28.00	129.00	222.00	18.83	-54.08	21.50	-60.00	6	67%	17.32	-57.10	4	100%
1980	138.9	36.00	74.57	165.43	19.63	-51.04	22.59	-56.67	7	71%	29.04	-46.34	5	100%
1981	159.2	20.25	117.75	207.00	20.29	-51.56	21.76	-54.28	8	100%	25.53	-64.33	6	100%
1982	142.4	21.00	72.00	135.00	21.12	-62.02	22.80	-64.15	4	50%	25.60	-71.00	1	100%
1983	152.3	10.00	72.00	128.00	27.83	-76.97	28.73	-76.87	3	67%	28.57	-83.23	3	67%
1984	105.0	24.00	51.00	138.60	23.46	-60.70	24.84	-61.49	10	60%	28.45	-66.60	2	100%
1985	153.1	24.75	91.50	184.50	22.33	-70.45	24.81	-71.74	8	62%	26.50	-75.10	5	80%
1986	136.1	8.00	44.00	216.00	21.50	-60.60	21.93	-61.97	3	67%	29.70	-65.00	2	100%
1987	115.3	26.57	87.43	205.71	16.70	-53.60	19.23	-56.76	7	71%	25.20	-64.07	3	100%
1988	144.0	33.82	87.82	139.09	19.25	-58.41	21.91	-62.75	11	36%	17.60	-73.08	5	40%
1989	131.2	21.00	75.00	111.00	15.30	-69.20	16.15	-73.10	2	0%	28.10	-94.60	1	0%
1990	132.2	30.00	99.00	188.40	16.68	-47.01	18.42	-52.01	10	50%	20.18	-58.87	6	33%
1991	140.9	21.00	59.00	151.00	22.15	-59.28	23.28	-61.58	6	83%	28.93	-68.00	3	100%
1992	175.0	24.00	105.60	214.80	26.66	-54.24	28.02	-57.50	5	60%	31.53	-53.20	3	67%
1993	126.4	24.00	93.43	150.86	17.14	-56.17	19.61	-58.41	7	43%	31.32	-67.55	4	75%
1994	111.8	13.50	33.00	102.00	16.00	-53.10	16.72	-54.33	4	0%	14.50	-46.80	1	0%
1995	164.3	22.20	79.80	231.00	17.14	-56.46	18.32	-58.75	10	60%	19.06	-57.40	7	86%
1996	165.2	47.33	122.00	252.67	14.74	-52.39	15.76	-60.19	9	67%	16.15	-60.33	6	83%
1997	123.1	16.00	84.00	188.00	18.37	-59.10	19.63	-59.93	3	100%	15.20	-53.70	1	100%
1998	169.3	20.00	83.00	226.00	18.24	-59.17	19.02	-61.61	12	67%	22.93	-52.83	9	89%
1999	176.9	18.00	92.40	197.40	15.67	-60.72	16.57	-63.17	10	60%	19.11	-62.63	7	86%
2000	140.9	27.00	90.43	166.71	18.85	-57.96	20.71	-61.64	14	56%	19.99	-59.31	8	62%
2001	157.5	37.80	111.00	180.60	17.92	-56.01	19.44	-62.79	10	60%	25.40	-67.28	6	83%
2002	129.0	19.09	81.27	159.27	24.02	-66.95	25.32	-69.63	11	27%	26.75	-71.85	4	50%
2003	162.8	26.25	98.25	244.50	18.85	-58.73	20.35	-61.07	8	50%	22.93	-45.42	4	50%
2004	168.5	28.50	135.00	244.00	15.97	-50.27	17.27	-56.08	12	57%	19.86	-52.74	8	75%
2005	165.2	22.40	85.60	182.00	20.11	-65.12	22.38	-66.84	15	53%	23.47	-74.23	10	60%
2006	147.2	22.29	84.86	248.57	16.13	-44.17	17.63	-48.73	7	71%	23.40	-59.98	5	100%
2007	145.8	27.00	79.80	141.00	18.77	-57.81	18.91	-61.07	10	10%	18.98	-71.17	6	17%
2008	150.7	9.60	69.00	190.80	17.98	-60.57	18.32	-61.69	10	60%	21.12	-66.76	5	100%
Standard Dev.	18.37	10.61	26.94	42.14	3.26	7.12	3.30	6.12	3.11	0.22	4.85	9.99	2.21	0.29
Covariance	-3.04	-2.69	-4.26	-0.27	0.37	0.12	0.28	0.56	-0.46	0.02	0.65	1.22	-0.30	0.03
Correlation	-0.27	**-0.41**	-0.26	-0.01	0.18	0.03	0.14	0.15	-0.24	0.12	0.22	0.20	-0.22	0.19
Spearman's	-0.22	**-0.34**	-0.20	-0.04	0.11	0.11	0.13	0.32	-0.26	0.12	0.26	0.16	-0.26	0.17