SOME CLIMATOLOGICAL ASPECTS OF TROPICAL CYCLONES IN THE EASTERN NORTH PACIFIC

Larry W. Schultz (retired)
Formerly with
NOAA/National Weather Service
Weather Forecast Office
Topeka, Kansas

Abstract

A climatological study of eastern North Pacific (ENP) tropical cyclones was conducted. The study included a few parameters not typically found in tropical cyclone climatologies. Among these were the yearly percentage of named storms reaching hurricane status and the yearly average maximum winds. Seven-year running means were constructed and clearly showed that cycles do exist in these as well as other parameters investigated. The data analysis suggested that cyclical changes in the El Nino-Southern Oscillation (ENSO) are associated with the cyclical nature of ENP tropical cyclones. Other parameters examined in this study included the time of the development of the first named storm of the year and its relationship to the total number of named storms in that year. Little correlation was found. When the number of tropical cyclones was divided into periods of ten- days or one third- monthly intervals, the greatest frequency of storms were found to occur during the latter third of August.

This research also includes a climatological study of tropical cyclones impacting the Hawaiian Islands. The data revealed a mean development area south of the mouth of the Gulf of California. A mean track was plotted and the intensity mean along this track was noted. The analysis showed that tropical cyclones generally are in a weakening trend as they approach the Hawaiian Islands, primarily bringing heavy rainfall and high surf. However, on occasion a tropical cyclone is sufficiently strong to produce damaging winds to the Islands.

Corresponding Author: Larry Schultz,
3618 SW 33rd Street, Topeka, KS 66614-2812
Email: schultzstringstorm@sbcglobal.net

1. Introduction

The eastern North Pacific (ENP) basin extends from the mainland of North and Central America westward to 140 degrees west longitude. Since an occasional ENP tropical cyclone ventures toward Hawaii, consideration, for the purpose of this study, is extended westward through the Hawaiian Islands or roughly to near 160 degrees west longitude. The ENP area is one of several regions around the globe where tropical cyclones occur on a regular basis. While much attention has been given by the meteorological community to tropical systems in the North Atlantic basin (e.g., Jarvinen et al. 1984; Landsea 1993), tropical systems in the ENP basin have received much less, despite on average being more frequent than their North Atlantic basin counterparts. This is understandable given the significant impacts Atlantic basin systems often have on the lives and economies of coastal regions in the United States, Mexico, and the nations of Central America.

Although not as frequent or generally as extensive as impacts generated by North Atlantic basin tropical cyclones, tropical cyclones originating in the ENP basin can produce significant impacts. Occasionally a tropical storm or hurricane will impact the Pacific Coast of Mexico, sometimes with devastating consequences. Hurricane Kenna in 2002 is a recent example (Franklin 2002). Tropical cyclones have also been known to produce substantial wind damage to the Hawaiian Islands as did Hurricane Fico in 1978 and Hurricane Iniki in1992. Also, from time to time, ENP tropical cyclones will move far enough north to make a significant contribution to the warm season rainfall climatology of the Southwest United States as documented in a State University of New York at Albany study (available online at: www.atmos.albany.edu). Because of these as well as other impacts and the relatively high numbers of ENP tropical cyclones, a study of their climatology was conducted which included some observations typically not considered in past research.

Section 2 of this paper shares the methodologies utilized to construct the climatology. Included in this research are the 7-year running means used to investigate cyclical trends in the frequency and intensities of tropical cyclones as well as and their possible relationship to phases in the El Nino-Southern Oscillation (ENSO). These as well as other related results are presented in section 3. Section 4 examines the tracks and intensities of tropical cyclones originating in the study's domain and whose centers passed close to the Hawaiian Islands. Finally, section 5 is a summary of the results.

2. Data and Methodology

a. Domain and data sources

The domain for this investigation of tropical cyclones lies in the eastern portion of the North Pacific basin (ENP) as previously defined in this paper. Tropical cyclone data for this study was obtained from the archives of the eastern North Pacific basin at the NOAA/NWS Tropical Prediction Center in Miami, available online at www.nhc.noaa.gov/pastall.shtml, and from Unisys Corporation available online at: http://weather.unisys.com/hurricane/e_pacific/. The NOAA/NWS Central Pacific Hurricane Center (CPHC) in Honolulu provided newspaper reports of tropical cyclones impacting the Hawaii Islands, available online at: www.prh.noaa.gov/cphc/summaries/.

b. Period of study and operational definition of tropical cyclone

The period of study for this research spanned 34 years. Although satellite coverage (Jarvinen et al. 1984) allowed for an accurate assessment of the total number of tropical cyclones in the ENP basin beginning in 1966, it wasn't until 1971 that a consistently accurate accounting for intensity was seen in issued advisories. Thus, the data used in this study dates from 1971 through 2004; however, there were three tropical cyclones during this period that were not included in the data sample since those systems reached tropical cyclone status in the Atlantic before emerging into the Pacific basin. *It is important to note that tropical cyclones included in the period of study were limited to named storms (i.e., those cyclones reaching tropical storm or hurricane strength).*

c. Seven-year running means

Several parameters for investigation were analyzed from the raw data and then subjected to a statistical procedure referred to as "running means" (Panofsky and Brier 1958). Running means is an averaging technique that allows for data, characterized by periodical oscillations on various scales, to be filtered or smoothed. The principal utility of such an analysis, as applied in this work, was to smooth out short-period fluctuations, allowing for potentially better clarity with respect to longer term climatological considerations that might otherwise be masked.

The time period chosen for a yearly mean in this research corresponds to the calendar year. There were no tropical cyclones included in this study that occurred before May or after December. The date of a tropical cyclone occurrence, relative to the calendar year, is predicated upon the date of the tropical cyclone birth. The date of the tropical cyclone birth was considered, for purposes of this paper, to be the time when the system was first officially designated as a tropical depression.

To further illustrate the calculation of running means, consider the parameter - frequency of tropical cyclone events. The total number of tropical cyclone occurrences in a calendar year was averaged over a period of seven years. This value was then assigned to the ending year of that time period. By repeating this process through advancing the calculations one year (both beginning and ending times), a 7-year running mean of the averages was created. Seven-year running means were calculated for a number of investigative parameters and are discussed in section 3.

While 5-year running means are often used in climatological calculations, this study compared tentative results by calculating the running yearly means for a 3,4,5,6 and 7 year period. The running means of three through six years showed too many short term fluctuations in the analysis. The 7-year running mean gave better clarity with respect to the longer-term cycles and their associated climatological considerations. Given these results, running means based upon eight years or more were not used, since longer term cycles begin to be smoothed out when using such large ranges.

d. Estimating tropical cyclone intensity

1) Yearly average maximum wind (YAMW)

Intensity values for tropical cyclones located in the ENP basin are nearly always based upon estimated values of pressure and maximum winds; however, there is a potential for large errors when using these means given that pressure estimates are made to the nearest millibar and maximum wind estimates are made in 5-knot intervals. The maximum sustained wind reached during the lifespan of a given tropical cyclone offers an alternative measure of storm intensity and generally with the potential for less error. In this study, the yearly average maximum wind (YAMW) is used as a measure of tropical cyclone seasonal intensity. Specifically as utilized here, the YAMW is defined as the sum of the maximum wind (knots) of each tropical cyclone per year divided by the total number of tropical cyclones in that year. Seven-year running means for the YAMW values were calculated for the period of study and represent an estimate of seasonal tropical cyclone intensity. The results are presented in section 3b. Wing et al. (2006) provides more information on the use of maximum wind in tropical cyclone climatology

2) Hurricane generation index (HGI)

The Hurricane Generation Index, defined in this research as the yearly percentage of storms reaching hurricane status, is used as a measure of tropical cyclone seasonal intensity. Seven year running means for HGI were calculated for the period of study. Results are presented in section 3b.

e. Determining ENSO conditions (Oceanic Nino Index)

One factor that may be an influence on the frequency and strength of ENP tropical cyclones is the presence of El Nino, La Nina, or neutral ENSO conditions. The Oceanic Nino Index (ONI) was used to define these conditions. Details on how this index is derived are available online at: www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml from the NOAA's Climate Prediction Center website. To allow time for the atmosphere to react to oceanic temperature changes, the period of March through August was chosen as the time interval for ONI index calculations. Based on an approximate 1 to 2 month delay in atmospheric adjustment to oceanic temperature changes during any ENSO phase (Simmons et al. 1983), it is believed that the March through August period of the ONI index would reflect atmospheric conditions best corresponding to the bulk of the eastern Pacific tropical cyclone season. The ONI indices are 3-month running means. To avoid a particular month from being considered more than once, it was decided to use only the 3-month indices for March, April, May, and for June, July, and August. These two indices were then averaged and the result was used as the index for the season. ONI values at or above +0.50 were classified as El Nino years; values at or below -0.50 were La Nina years; and values ranging from -0.49 to +0.49 were classified as neutral years.

3. Cyclical Trends in Tropical Cyclones and Other Climatological Insights

a. Trends in frequencies of tropical cyclones, hurricanes, and severe hurricanes

The ENP tropical cyclone season is from May 15 to November 30. A total of 517 tropical cyclones (i.e., named storms) occurred during the 34 year study period (1971-2004). This equates to an average of 15.2 tropical cyclones per year. The 7-year running means for the total yearly number of tropical cyclones, the number of hurricanes, and the number of severe hurricanes, defined, for the purposes of this study, as categories 4 and 5 on the Saffir-Simpson Scale (Simpson 1974), are shown in Fig. 1. This filtered data indicates that the number of tropical cyclones peaked around 1987. It is possible that the relatively low frequency in activity seen in 2002 represents a minimum, although more data is needed from at least the next few years to further support this.

The number of hurricanes peaked around 1995 according to Fig. 1, while the number of severe hurricanes peaked around 1998. Note that the peak in severe hurricanes coincides closely to the minimum number of tropical cyclones. This suggests that during minimum cycles of activity tropical cyclones tend to be fewer, but more intense; the data also hints that during times of maximum activity, the tendency is toward more tropical cyclones, but of weaker strength. More data is needed in future years before confirmation of these initial findings can be better established.

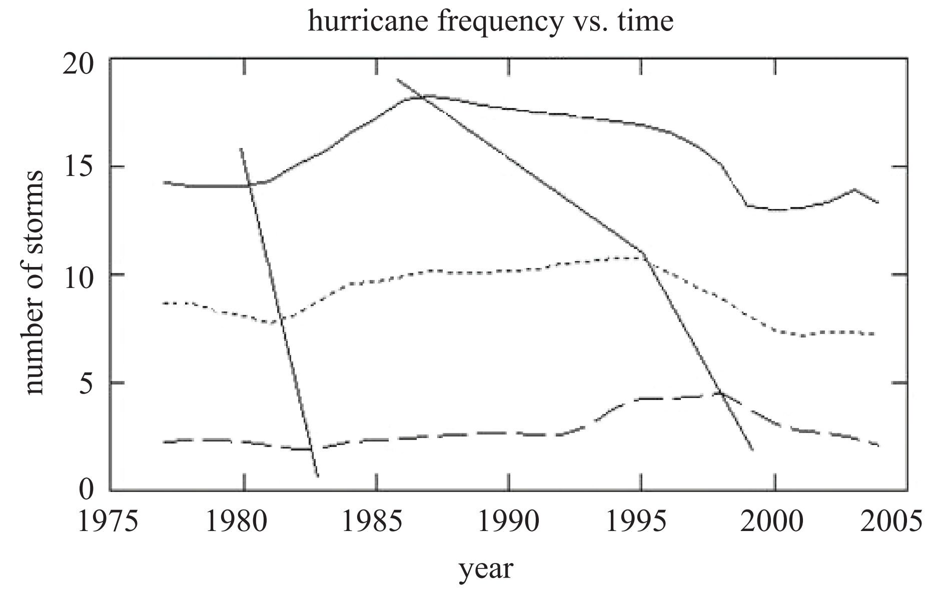

Fig. 1. Seven-year running means for the total yearly number of tropical cyclones (solid upper line), hurricanes (dashed middle line), and severe hurricanes (dashed bottom line) are plotted from left to right for the period of study. The slanted vertical lines are axes of minimum (left) and maximum (right) activity as signaled in the 7-year running means.

b. Trends in hurricane intensities

Figure 2 shows the 7-year running means for the YAMW, representing an estimate of seasonal tropical cyclone intensity. Note there are a number of short term cycles superimposed on the larger cycle. This larger cycle appears to also coincide closely to the cycle of severe hurricanes (Fig. 1). Also, note that the maximums seen in the number of severe hurricanes (Fig. 1) and in the highest values (around 80 knots) of YAMW (Fig. 2) all occur near a minimum in the number of tropical cyclones (Fig. 1).

The yearly percentage of tropical cyclones to reach hurricane status (Fig. 3) and to reach severe hurricane status (Fig. 4), as revealed by their 7-year running means, peaked during the 1990's before significantly decreasing. Note that both peaks occurred near a period of fewer tropical cyclones (Fig. 1). Also a comparison of Fig. 4 with Fig. 1 shows a trend for an increase in severe hurricanes to be more common near the minimum in the frequency cycle of tropical cyclones. Again, more data is needed before these signals in the cyclical trends can be better resolved.

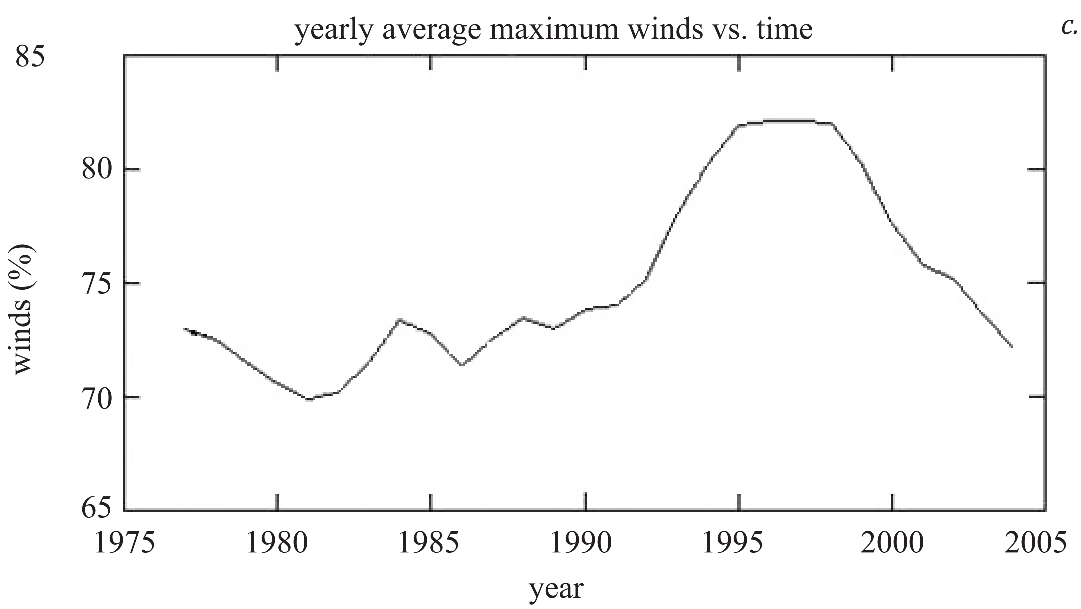

Fig. 2. Seven-year running means of yearly average maximum winds (YAMW) of named tropical cyclones.

c. Trends in the ENSO

ONI values, as detailed in section 2 of this paper, were employed to determine the ENSO phase for a given year. Table 1a shows for each year in the 34-year period of study, the ONI values for March-August, the associated ENSO phase category, and the total number of named tropical cyclones. Table 1b provides the average number of named tropical cyclones per year for the three phases of the ENSO - El Nino, La Nina, and neutral. Note that during the 34 year period of study, Table 1b shows that 10 years were classified as El Nino years; 9 were noted as

La Nina, and 15 were found to be neutral. The average number of tropical cyclones for the El Nino, La Nina, and neutral years was 16.9, 15.4 and 13.9 respectively. Considering the average number of tropical cyclones per year for the entire 34 year study period was 15.2, the data suggests that tropical cyclones in the ENP basin were slightly more active during the El Nino phase, less active during the neutral phase, and near normal during the La Nina phase.

Of interest, Lupo and Johnston (2000) studied the occurrence of hurricanes in the North Atlantic basin as related to ENSO conditions. They found that hurricanes seem to be more frequent during La Nina years and that they were at a minimum during El Nino years. These results were generally not in agreement with the results found for the ENP basin. However, Lupo and Johnston investigated only the frequency of hurricane occurrence, and not the frequency of all named tropical cyclones as was done here.

When the ONI index values were readjusted (able 1c) requiring higher values for classification as an El Nino year (at or above +0.70), lower values (at or below -0.70) for La Nina, and a larger range in the ONI values (at or between -0.20 and +0.20) for neutral years; the weaker El Nino and La Nina events were then reclassified as neutral. These readjusted ONI values were meant to reflect the number of tropical cyclones associated with the stronger El Nino and La Nina events. The results from Table 1c presented a more significant trend. Moreover, for the stronger El Nino years the average number of tropical cyclones increased from 16.9 to 18.6; for the stronger La Nina years the average decreased from 15.4 to 14.2; and for the neutral years the average was readjusted to 12.3. Due to the limited period of study, definitive conclusions cannot be drawn from these results. However, these results do show trends that at least suggest an influence of ENSO conditions on the yearly number of tropical cyclones.

Of course, there are additional elements that are likely factors in the occurrence of ENP tropical cyclones such as mid-tropospheric wind flow patterns across the Central American mountain ranges. Specifically, it is

Year	*Number of tropical cyclones*	*ONI INDEX (March - Aug.)*	*Category*
1971	17	- 0.90	La Nina
1972	12	+0.70	El Nino
1973	12	- 0.60	La Nina
1974	17	- 0.80	La Nina
1976	14	- 0.30	Neutral
1977	08	+0.20	Neutral
1978	18	- 0.35	Neutral
1979	10	+0.10	Neutral
1980	14	+0.20	Neutral
1981	15	- 0.35	Neutral
1982	19	+0.60	El Nino
1983	21	+0.70	El Nino
1984	19	- 0.35	Neutral
1985	22	- 0.60	La Nina
1986	17	0.00	Neutral
1987	18	+1.25	El Nino
1988	12	- 0.75	La Nina
1989	17	- 0.60	La Nina
1990	20	+0.30	Neutral
1991	14	+0.65	El Nino
1992	25	+0.90	El Nino
1993	14	+0.65	El Nino
1994	17	+0.55	El Nino
1995	10	+0.20	Neutral
1996	08	- 0.20	Neutral
1997	17	+1.05	El Nino
1998	13	+0.15	Neutral
1999	09	- 0.80	La Nina
2000	17	- 0.65	La Nina
2001	15	0.00	Neutral
2002	12	+0.65	El Nino
2003	16	+0.20	Neutral
2004	12	+0.45	Neutral

Table 1a. Yearly ONI values for the March through August period and the yearly number of ENP named tropical cyclones associated with each phase of the ENOS for the complete 34-year period of study.

	ONI	Average number tropical cyclones
El Nino years 1971-2004	> +0.49	16.9 (10)
La Nina years 1971-2004	< - 0.49	15.4 (09)
Neutral years 1971-2004	-0.49 to +0.49	13.9 (15)

Table 1b. Average number of named tropical cyclones per year associated with the phases of ENSO as determined by standard ONI values. Numbers in parentheses indicate total years in each ENSO phase during the 34 year period of study.

	ONI	Average number tropical cyclones
El Nino years 1971-2004	> +0.69	18.6 (5)
La Nina years 1971-2004	< - 0.69	14.2 (5)
Neutral years 1971-2004	-0.20 to +0.20	12.3 (9)

Table 1c. Same as in Table 1b except the ONI values were readjusted to reflect the average number of tropical cyclones per year associated with the stronger El Nino and La Nina phases.

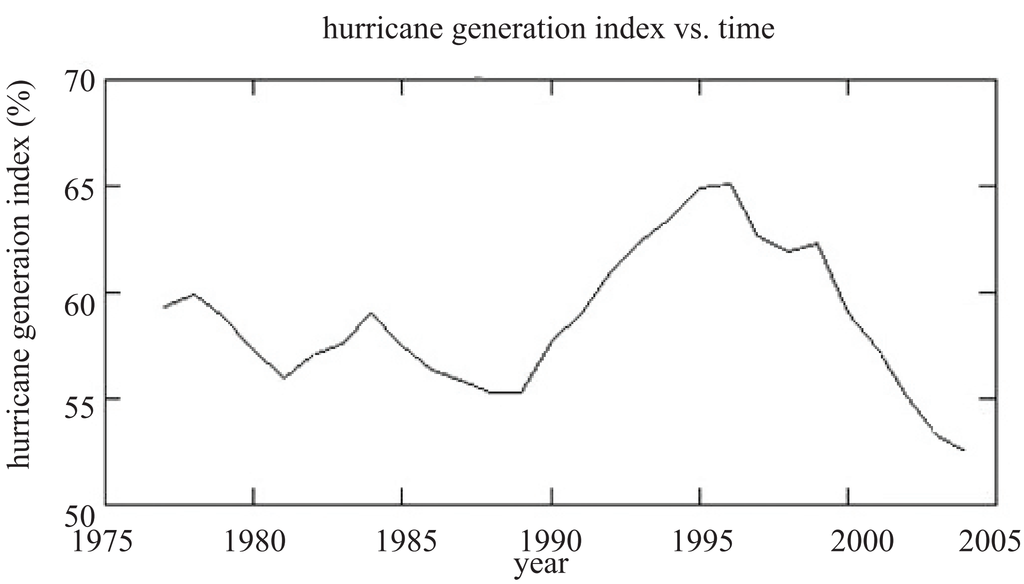

Fig. 3. Seven-year running means of the percentage of named tropical cyclones to reach hurricane strength (Hurricane Generation Index).

	May	June or July
1971-2004 study period	15.4 (19)	15.0 (15)

Table 2. Average number of named tropical cyclones per year as a function of the first developmental month. Numbers in parentheses indicate total years in the data sample.

well known in the meteorological community that middle and upper tropospheric winds, which blow at some angle to mountain ranges, tend to create areas of lower surface pressure on the lee side (Barry 1992; Holton 1992). Moreover for any given wind speed, the more perpendicular to the mountain range the wind flow pattern, the more pronounced the lee low pressure area will be. Assuming the mid and upper level winds are not so strong as to induce significant shear, then lee cyclogenesis may help to explain why some easterly waves, moving across the Atlantic Ocean in relatively benign fashion, become active after crossing Central America into the eastern Pacific (Pasch 2002); and why some attending surface circulations may develop or strengthen within the easterly waves shortly after the crossing is made (Stewart 2004). More study on this matter is needed before definitive conclusions can be made.

d. Time of onset of first tropical cyclone and cyclone frequency

Table 2 compares the average number of named tropical cyclones per year for the 34-year period of study to the month in which the first tropical cyclone of the season formed. The analysis shows that when the first named storm forms during the month of May (June or July), a yearly average of 15.4 (15.0) named storms occurred. Such small differences in average yearly tropical cyclone frequencies are not significant. This is not surprising since the window of opportunity for development has been shortened only slightly as a result of the later onset of initial development. As a side note, it is interesting that through 2006, the ENP Basin had 7 consecutive years in which the first named tropical cyclone formed during the month of May.

e. Favored periods for tropical cyclone formation

As a means to investigate the most probable climatological period for tropical cyclone formation in the ENP, the period of study was divided into 10-day or one-third monthly intervals. A 10-day interval was chosen, rather than monthly, so that any favored development periods might become more apparent. Table 3 shows the tropical cyclone season divided into 10-day intervals, the total number of tropical cyclone formations, and the average number of tropical cyclones that occurred for the 10-day intervals during the 34-year period of study. A close inspection of the data in Table 3 for the months of July through September shows definite peaks in tropical cyclone development during the latter third of each of those months. Note that the overall peak in tropical cyclone formation during the 34 year period of study occurred in the latter third of August. Perhaps these periodic peaks and lulls in developments that occur within the tropical cyclone season are reflections of normal synoptic pattern changes that typically occur each year.

Regarding the periods with a minimum of tropical cyclone formations, Table 3 shows the least number of tropical cyclone formations occurred at the onset and near the conclusion of the official ENP tropical cyclone season (May 15-November 30) as expected. The 34 year period of study shows that there were only 8 tropical cyclones to develop during the month of November, while only 3 occurred after 10 November and only 1 during the first third of December. If these findings represent an established tendency, then perhaps an earlier ending date to the eastern North Pacific tropical cyclone season could be considered. If the season were to end after the first third of November; then only one named storm would typically be expected in the revamped post-season about every 9 years.

Date	*Total*	*Average per year*
May 11 – 20	06	0.18
May 21 – 31	14	0.41
June 01 – 10	18	0.53
June 11 – 20	26	0.76
June 21 – 30	24	0.71
July 01 – 10	38	1.12
July 11 – 20	43	1.26
July 21 – 31	46	1.35
August 01 – 10	34	1.00
August 11 – 20	36	1.06
August 21 – 31	54	1.59
September 01 – 10	33	0.97
September 11 – 20	39	1.15
September 21 – 30	36	1.06
October 01 – 10	29	0.85
October 11 – 20	16	0.47
October 21 – 31	17	0.50
November 01 – 10	05	0.15
November 11 – 20	02	0.06
November 21 – 30	01	0.03
December 01 – 10	01	0.03

Table 3. Total number of ENP tropical cyclone formations and the average number of tropical cyclones that occurred for one-third monthly intervals during the 34-year period of study.

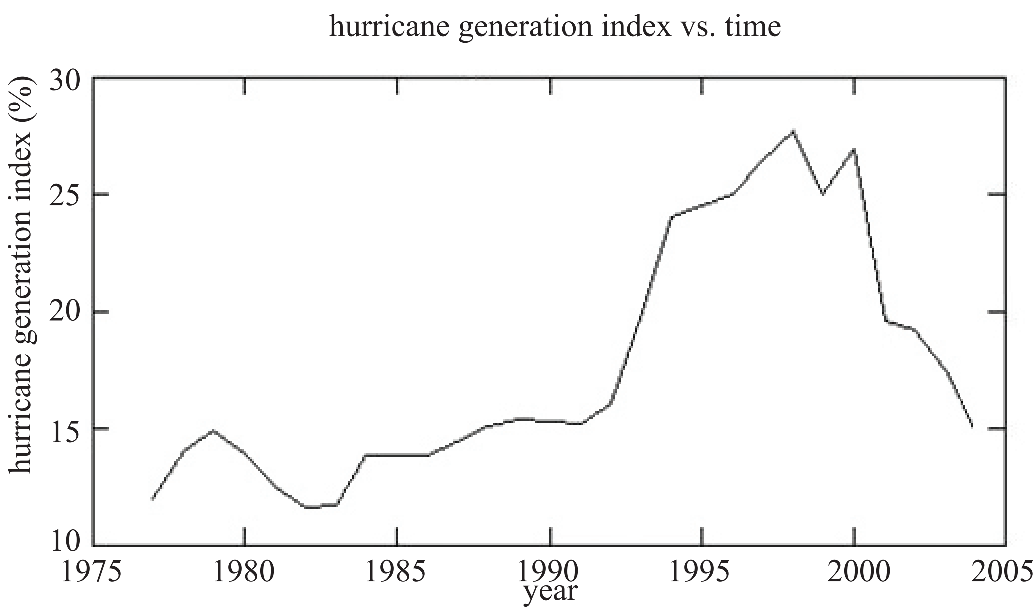

Fig. 4. Same as Fig. 3 except for severe hurricanes.

4. Tropical Cyclones Passing near Hawaii

Occasionally, ENP tropical cyclones move westerly to near the Hawaiian Islands. For this portion of the study, all (i.e., not just named storms) tropical cyclones whose center passed within 2.5 degrees latitude of any of the eight major Hawaiian Islands, were considered. There were a total of 20 such tropical cyclones during the 1971 through 2004 study period, averaging less than one per year. The intensities of these "near to Hawaii" storms varied from tropical depression status to major hurricanes.

ENP storms impacting the Hawaiian Islands tend to develop to the south of the mouth region of the Gulf of California. Figure 5 shows a map of the mean track of tropical cyclones that moved westerly to the Hawaiian Islands, while Fig. 6 shows the average maximum winds of storms along this track. Note that storms from the eastern Pacific usually peak, in intensity, well to the east of the Islands, and typically are undergoing a general weakening trend upon reaching Hawaii.

The primary impact of ENP tropical cyclones approaching Hawaii is heavy rainfall and higher than normal surf as well as an increase in trade wind speeds. Infrequently, tropical cyclones are of sufficient intensity and proximity to produce damaging winds to the Islands. During the study period there were six such storms.

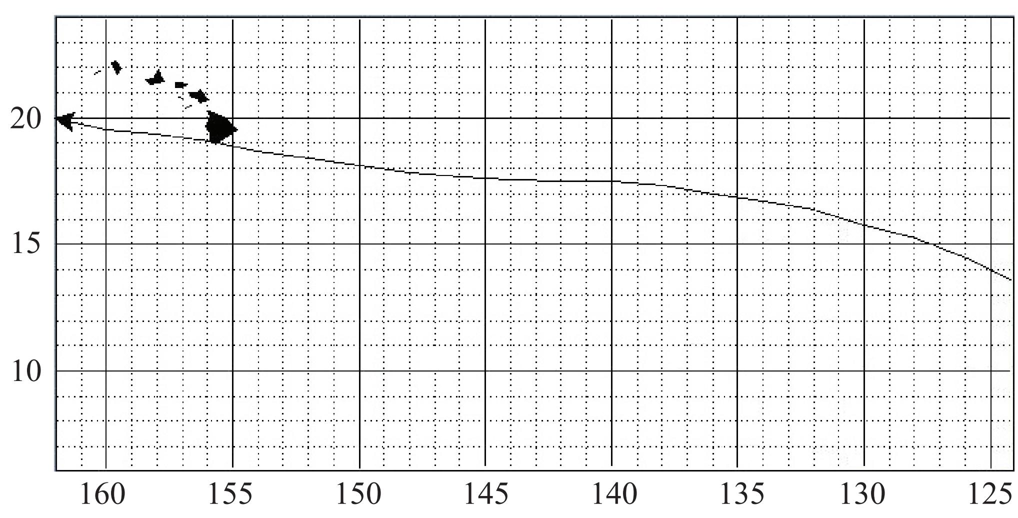

Fig. 5. Mean track of tropical cyclones form the eastern North Pacific to near the Hawaiian Islands. The abscissa is degrees W and the ordinate is degrees N.

5. Summary

This climatology of tropical cyclones in the eastern North Pacific found various cycles in storm activity. The seven-year running means of the data suggest that during cycles of low activity, storms appeared to be more intense; while during periods of high activity, storms were (on the average) of weaker intensity. The study also suggests that there is an ENSO relationship regarding tropical cyclone development. El Nino periods were found to be associated with the largest annual numbers of named storms. Somewhat surprisingly, those years featuring a "neutral" phase in the ENSO had the least frequency during the 34-year study period (1971-2004).

Analysis of the data also revealed relatively low frequency of tropical cyclone activity during the month of November. It is possible that an earlier end to the official ENP season may be desirable, if these relative frequencies of tropical cyclone formations continue. Stratifying the data into 10-day intervals indicated the favored periods of development during the tropical cyclone season. The latter third of August was found to be the overall peak period for development of tropical cyclones in the ENP basin.

With respect to Hawaii, an eastern North Pacific tropical cyclone will occasionally move westward to affect the Hawaiian Islands. These cyclones normally develop in the area south of the mouth of the Gulf of California and are usually on a weakening trend by the time of their approach to Hawaii. Their main impacts on the Islands are typically high surf, heavy rains, and an increase in the trade winds. Infrequently, the storms are of sufficient strength and proximity that they do produce damaging winds in Hawaii.

Finally, this climatology provided trends in ENP tropical cyclone frequency, intensity, and a possible connection to the phases of the ENSO as well as other insights. However, additional data is needed beyond this period of study (2004) before definitive conclusions can be made.

Author

Larry W. Schultz graduated from Oklahoma University with a B.S. in Meteorology in 1971. During his college years, he worked 3 summers at the U.S. Weather Bureau/ National Weather Service Office in Dodge City, KS. Upon graduation, he interned at St. Cloud, MN and Milwaukee, WI, before being assigned as a forecaster to the National Weather Service Forecast Office in Topeka, KS, in 1977, where he worked until retirement, in December 2004. Born and raised in central Kansas, he developed an early childhood interest in weather with special interest in tornadoes and hurricanes. Several of his previous research works on various Kansas weather topics have been published as National Weather Service Central Region Research Papers, in the *National Weather Digest*, and in the *Bulletin of the American Meteorological Society*. He is also interested in astronomy, earthquakes, tsunamis, and volcanoes. He plans to divide his retirement time among: scientific research, managing the small family-farm in Central Kansas, and helping his wife, LeAnne Baehni-Schultz, in her professional career as teacher of music and as a Classical Violinist in the Topeka Symphony Orchestra.

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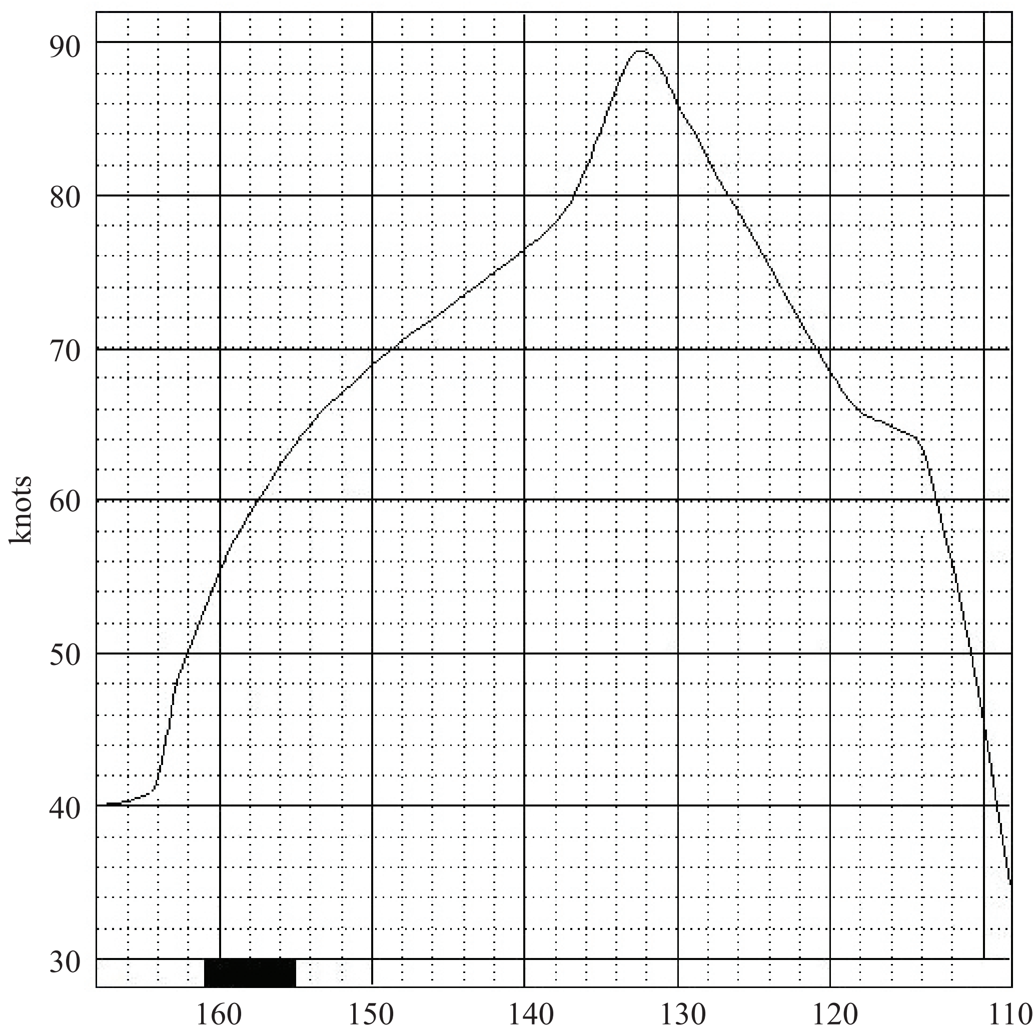

Fig. 6. Average wind sustained wind speed (knots) along the mean track of tropical cyclones from south of the Gulf of California mouth to near Hawaii. Shaded area is the Longitudes of the eight major Hawaiian Islands.

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