Climatic Atlas of Tropical Cyclone Tracks over the Central North Pacific

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Prepared in cooperation with

Hawaii CZM Program
Coastal Zone Management

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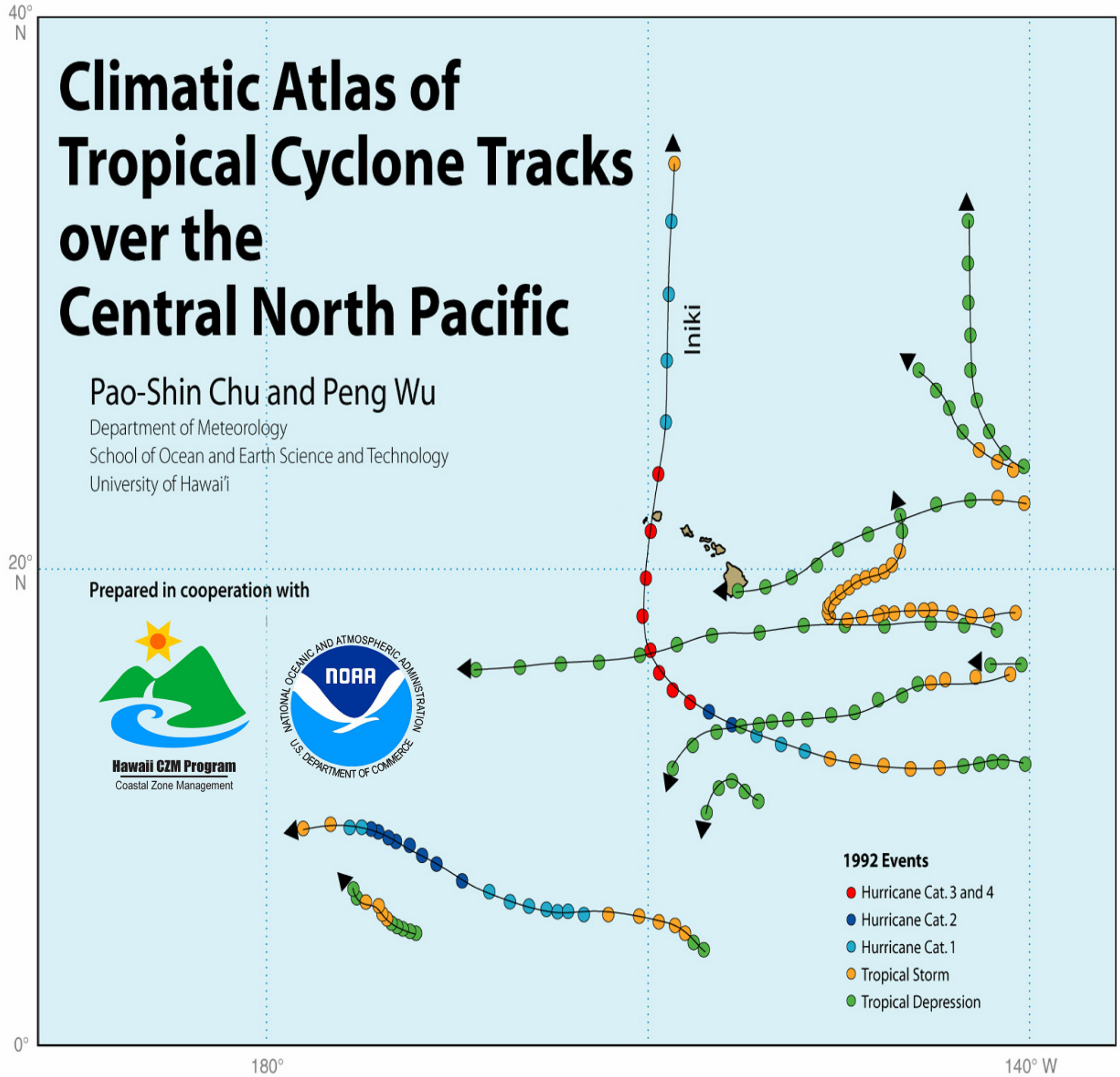

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Office of Planning
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and

NOAA/National Weather Service
Central Pacific Hurricane Center, Honolulu

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Preface

The purpose of this report is to document the history of tropical cyclone tracks over the central North Pacific and large-scale environmental conditions conducive for tropical cyclone development and path. Over the past 40 years, tropical cyclones have caused injury, loss of life, and enormous property damage. Because of the socio-economic repercussions of tropical cyclones, particularly from Hurricane Iniki in 1992 and the close encounter of three most intense hurricanes in 1994, there is a heightened level of awareness of the threat from tropical cyclones. Climate information about tropical cyclones is useful for land use planning, emergency management, hazard mitigation, and coastal resources protection. This atlas is intended for decision makers in many fields, including but not limited to federal, state, city and county government agencies, power utilities, schools, media, and others.

Acknowledgments

We are grateful to the Hawaii State Hurricane Advisory Committee and the State Civil Defense Agency for their support of this project. Andy Nash of the National Weather Service Forecast Office in Honolulu and Matt Sitkowski of the Department of Meteorology of the University of Hawaii provided assistance on the revised track records. Thanks are also due to Andy Nash and Kevin Kodama of the National Weather Service Forecast Office in Honolulu for invaluable suggestions that led to improvements in the report. Cynthia Dettmer of the Department of Meteorology at the University of Hawaii assisted us with data verification, file management, and graphics modification. And last, but not the least, we thank Ann Ogata-Deal of the Hawaii Coastal Zone Management Program of the Department of Business, Economic Development and Tourism for her gracious style in managing this project.

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1 . Introduction

The tropical cyclone (TC) is one of the most destructive natural disasters that cause loss of lives and enormous property damage around the world every year. In the past 50 years, four hurricanes (Iniki, Iwa, Dot, and Nina) have stricken the Hawaiian Islands (Schroeder, 1993), the most devastating being Iniki in September 1992 and Iwa in November 1982. Estimates of wind and high water damages were about $2.5 billion for Iniki and $250 million for Iwa. Considering the annual inflation, the damage would have been $3.19 billion for Iniki and $494.5 million for Iwa in 2005, according to the Honolulu Consumer Price Index. Iniki was a minimum category four hurricane on the Saffir-Simpson scale while Iwa was a category one hurricane. See the Glossary for various scales of TC intensity. In 1994, two years after Iniki, three category five hurricanes (Emilia, Gilma, and John) were observed over the central North Pacific (CNP). According to the National Weather Service, CNP is defined as a region between 140°W and the dateline and to the north of the equator. This is the first time that a category five (i.e., most intense) hurricane has been reported in the CNP since the reliable records began in 1966 (Garza et al., 1995), let alone three in a single season.

Shaw (1981) performed a laudable compilation of TC in the CNP for the period 1832-1979. However, the TC reports prior to 1966 over the CNP are thought to be less reliable because satellite observations were not in sufficient quantities (Mayfield and Rappaport, 1992). In addition, there is better understanding about TC tracks and variability over the CNP than there was 25 years ago (Chu and Wang, 1997; Chu, 2002; Clark and Chu, 2002; Chu and Zhao, 2004). Understanding TC track variability is important for land use planning, emergency management, hazard mitigation, and coastal resources protection. For all these reasons, the purpose of this atlas is to produce an updated and colorful atlas of TC tracks and characteristics (e.g., historical passage frequency) for the period 1966-2003. Environmental parameters pertinent to TC genesis and intensification will also be presented.

2 . Tropical Cyclone Data

2.1 Data Sources

Data for TC tracks are available from the National Hurricane Center and can be obtained from the website of the Central Pacific Hurricane Center (CPHC): http://www.prh.noaa.gov/cphc/summaries/. The data sets contain measurements of TC center location in latitude and longitude, one-minute sustained maximum wind speed, and central pressure (for most recent years) at 6-hour intervals for all TCs in the Central North Pacific (CNP). Based on the sustained maximum wind speed, TCs are grouped into seven categories, which include Hurricane Category 1-5, Tropical Storm, and Tropical Depression. The period of analysis is 1966 to 2003.

2.2 Data Corrections

The TC track data sets were revised by the CPHC. Based on their revisit to archived satellite images and historical records, a total number of six TCs were added into the data sets, five of these being during the early period of 1966 to 1980. Among the six TCs added, one is unnamed Hurricane in 1975, one is Tropical Storm Winona in 1989, and the other four are Tropical Depressions. In addition to the added TC counts, TC tracks became smoother (e.g., Hurricane Fico in 1978), and TC intensity (e.g., Hurricane Sarah in 1967 was upgraded from category 1 to 2) were revised in the data sets.

3 . General Climatology

3.1 Overall TC Statistics

Two types of TCs appear in the CNP. The TC counts include storms that form within the CNP as well as those that originate in the eastern North Pacific and subsequently propagate westward into the CNP. Table 3.1 shows the overall TC statistics. From 1966 to 2003, 166 TC occurrences were identified in the CNP. Out of these 166 TCs, 57 formed in the CNP (34%) and 109 moved into the region (66%). During this entire 38-yr period, the average number of annual TCs is 4.4 and the standard deviation is 2.9.

The official hurricane season in the CNP runs from June through November. During this six-month period, 161 TCs were reported (97%) out of an overall total of 166 occurrences. Historically, only 1 TC was observed in June (Table 3.1). The peak season is July-September when 140 TCs occurred (84%). In the following months (October to November), the CNP saw 20 TCs in the late season (12%). August is the month characterized by the most activity with 68 counts (41%).

As compared to the 161 TCs that occurred in the six-month period from June through

November, only 5 TCs were reported in other months during the 38-yr period. These 5 TCs were: Tropical Storm Carmen occurred in April 1980, Tropical Storm Winona in January 1989, Hurricane Ekeka in January 1992, Tropical Storm Hali in March 1992, and Tropical Storm Paka in December 1997.

Table 3.1 Overview TC Statistics

	June	July	August	September	October	November	Seasonal Total	Annual Total
1966	0	0	2(1)	2	0	0	4(1)	4(1)
1967	0	2	0	1	1	0	4	4
1968	0	2	4	1	0	0	7	7
1969	0	0	0	0	0	0	0	0
1970	0	0	2	1(1)	0	0	3(1)	3(1)
1971	0	1(1)	2	0	0	0	3(1)	3(1)
1972	0	0	3(3)	2	1	1(1)	7(4)	7(4)
1973	0	1(1)	0	0	1	0	2(1)	2(1)
1974	0	0	3(1)	0	0	0	3(1)	3(1)
1975	0	0	0	1(1)	0	0	1(1)	1(1)
1976	0	2	1	1(1)	0	0	4(1)	4(1)
1977	0	0	0	0	0	0	0	0
1978	0	1(1)	5(1)	0	1(1)	0	7(3)	7(3)
1979	0	0	0	0	0	0	0	0
1980	0	0	0	1(1)	0	0	**1(1)**	**2(1)**
1981	0	0	1	1	0	0	2	2
1982	0	3(1)	3(2)	3	0	1(1)	10(4)	10(4)
1983	0	0	3	1	2(1)	0	6(1)	6(1)
1984	0	1	3(1)	1	0	0	5(1)	5(1)
1985	0	2(1)	3	2(2)	1(1)	0	8(4)	8(4)
1986	0	3(1)	2	2(1)	0	0	7(2)	7(2)
1987	0	1	2	1(1)	0	0	4(1)	4(1)
1988	0	1	3(2)	1	0	0	5(2)	5(2)
1989	0	3(1)	1	0	0	0	**4(1)**	**5(1)**
1990	0	0	2	1(1)	1	0	4(1)	4(1)
1991	0	1	1(1)	0	1(1)	0	3(2)	3(2)
1992	0	2	1	3(1)	2	1	**9(1)**	**11(2)**
1993	0	2	3(2)	0	0	0	5(2)	5(2)
1994	0	4(2)	4(3)	2	1	0	11(5)	11(5)
1995	0	1	0	0	0	0	1	1
1996	0	0	1	1	0	0	2	2
1997	0	3	2	1	2	0	**8**	**9**
1998	0	1(1)	2	0	0	0	3(1)	3(1)
1999	0	1	2(2)	0	0	0	3(2)	3(2)
2000	0	2(1)	2	0	0	0	4(1)	4(1)
2001	1	0	0	2	1	0	4	4
2002	0	0	3(1)	0	2(1)	0	5(2)	5(2)
2003	0	0	2(1)	0	0	0	2(1)	2(1)
Average	0.03	1.05(0.29)	1.79(0.55)	0.84(0.26)	0.45(0.13)	0.08(0.05)	4.24(1.29)	4.37(1.32)
Climatological Total	1	40(11)	68(21)	32(10)	17(5)	3(2)	161(49)	166(50)

Note: TC occurrences are counted for each month in June-November during the 38-yr period. The seasonal total refers to the number of occurrences from June through November, whereas the annual total is the number of occurrences for the entire year. Numbers in the parentheses are the counts for hurricanes only. Seasonal and annual totals are bolded for the years when TCs occurred out of the hurricane season.

3.2 Temporal Variations of TC Occurrences

During the 38-year period, the total number of TCs observed during each 5-day period from June through November is plotted in Figure 3.1. Peaks of the TC abundance occur during mid-July through late August. To illustrate the interannual variability of TC activity, TC occurrence frequency during each official hurricane seasons of the 38 years are shown in Figure 3.2. No TC was reported in 1969, 1977, and 1979, whereas 1994 experienced as many as 11 TCs in the hurricane season.

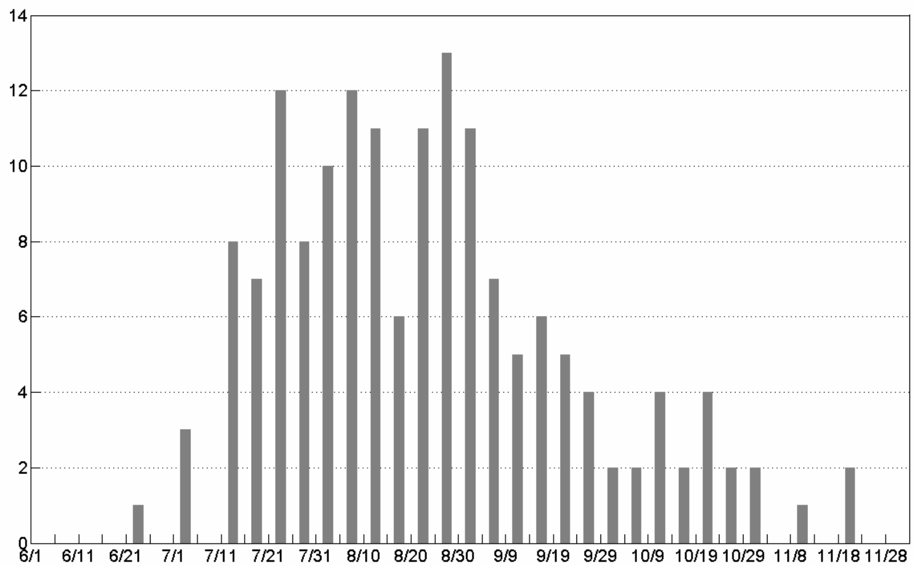

Figure 3.1. Annual cycle of TC occurrences. Numbers of TCs observed in the CNP during 1966-2003 are shown for each 5-day period from June through November. The x axis labels indicate the starting date of the corresponding 5-day period. 5 TCs occurred in other months (refer to Table 1) are not included.

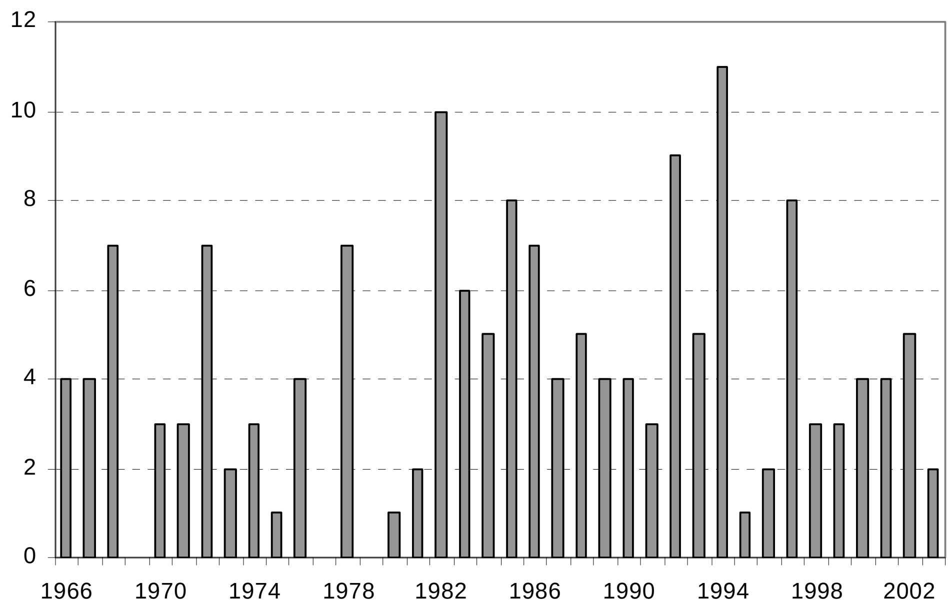

Figure 3.2. Number of TCs observed for 38-yr period. Number of TCs observed over the CNP in the hurricane season (June through November) during the 38-yr period.

4 . TC Tracks

TC tracks are plotted for each year from 1966 to 2003 (Figure 4.1-4.38). A table below the track for each individual year lists the duration and maximum intensity (knots) of each system. The starting date refers to the date when the system first appeared in the CNP. For the track maps, the 6-hourly positions of TCs are denoted with colored circles. As stated in the legend of each plots, red circles stand for Hurricanes of Categories 3, 4, and 5, ultra blue for Hurricane Category 2, sky blue for Hurricane Category 1, gold for Tropical Storm, and light green for Tropical Depression. 6-hourly positions through each TC are connected with a solid line to indicate the path. Each TC of at least tropical storm intensity is labeled with a name, and the final direction of movement is indicated by a solid black triangle next to its end point. Following the plots based on a yearly basis, TC tracks are also plotted for each decade of the 1970s (Figure 4.39), 1980s (Figure 4.40), 1990s (Figure 4.41), and for the entire 38-year period (Figure 4.42).

Tropical cyclones generally move around the periphery of the subtropical high pressure ridge. With a quasi-permanent high-pressure area situated just to the north of Hawaii in summertime, as will be seen clearly in section 6.2, a cluster of east-to-west tracks confined between 10°N-20°N over the CNP is evident (e.g., Figure 4.29). This westward movement of the TCs is reflected by the surrounding easterly trade flows in the tropics. However, some TCs tend to deviate from this canonical track pattern and move northwestward in response to occasional weakening of the subtropical ridge that affects deep layer mean flows. The latitudinal variation of the Coriolis force (the so-called β effect) across the storm's breadth also affects TC tracks. More often, recurvature of individual TC is caused by the approaching upper-level troughs of low pressure. Once TCs reach 30°N or beyond, they encounter midlatitude westerlies that steer them eastward. Entering into higher latitudes, TCs weaken rapidly or transformed into extra-tropical cyclones as ocean water becomes cold.

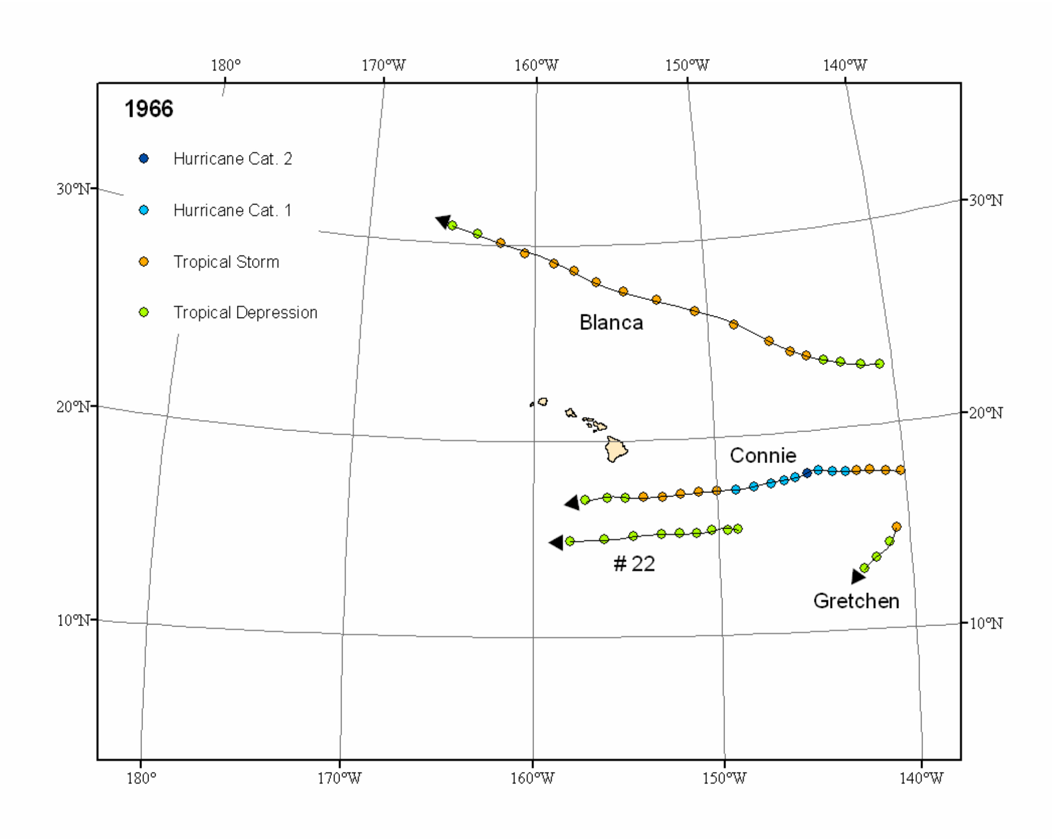

Figure 4.1. TC Tracks for 1966.

Name	Starting Date	Ending Date	Max Wind Speed
Blanca	8/7	8/12	45
Connie	8/12	8/17	85
# 22	9/10	9/12	25
Gretchen	9/11	9/12	35

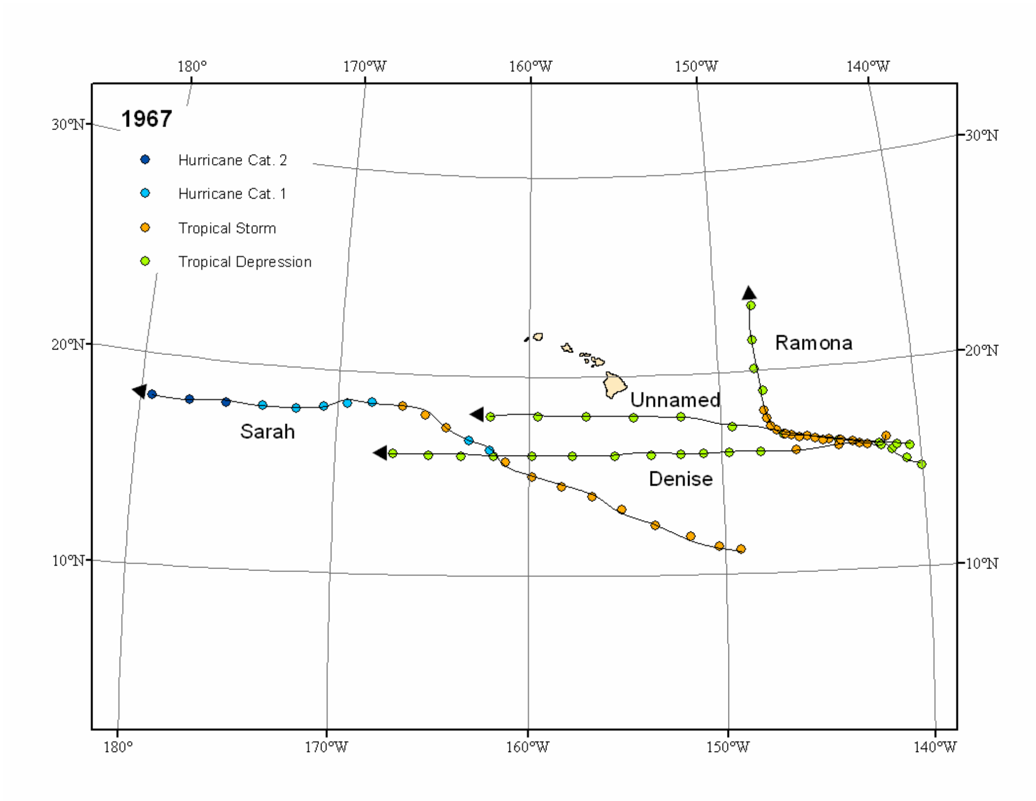

Figure 4.2. TC Tracks for 1967.

Name	Starting Date	Ending Date	Max Wind Speed
Unnamed	7/5	7/8	25
Denise	7/14	7/18	45
Sarah	9/8	9/14	95
Ramona	10/29	11/3	45

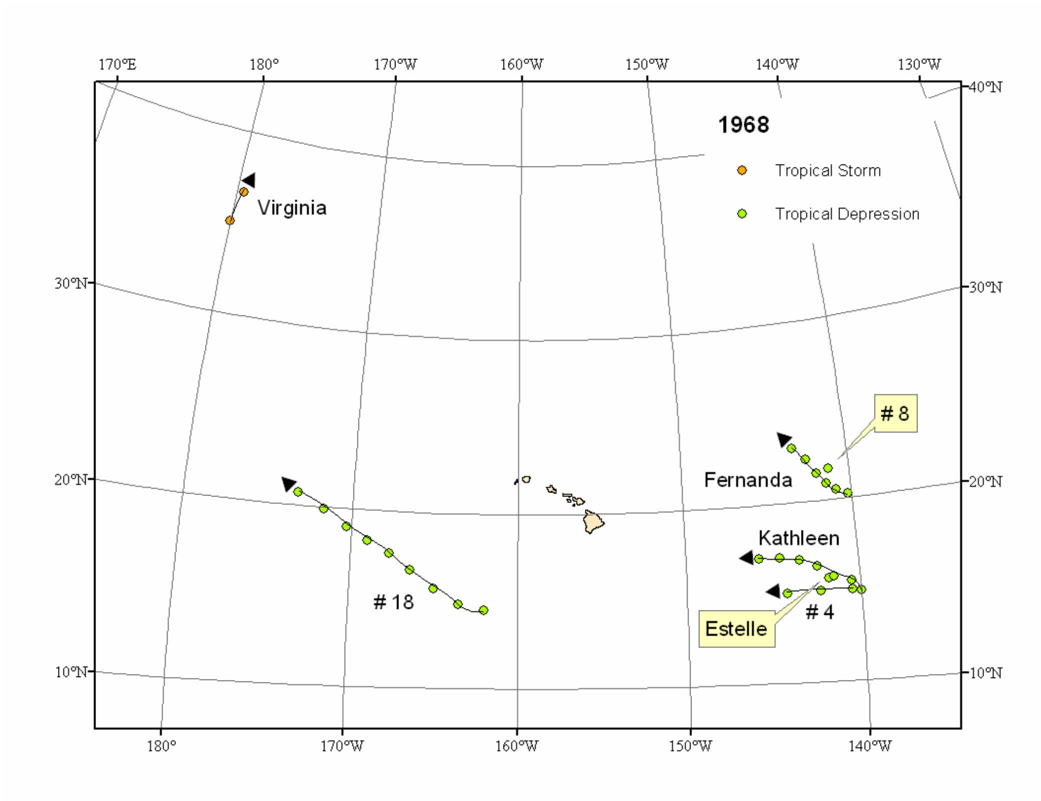

Figure 4.3. TC Tracks for 1968.

Name	Starting Date	Ending Date	Max Wind Speed
# 4	7/14	7/14	25
Estelle	7/31	7/31	25
# 8	8/1	8/1	25
Fernanda	8/13	8/15	25
Kathleen	9/1	9/3	25
Virginia	8/25	8/25	50
# 18	8/30	9/1	25

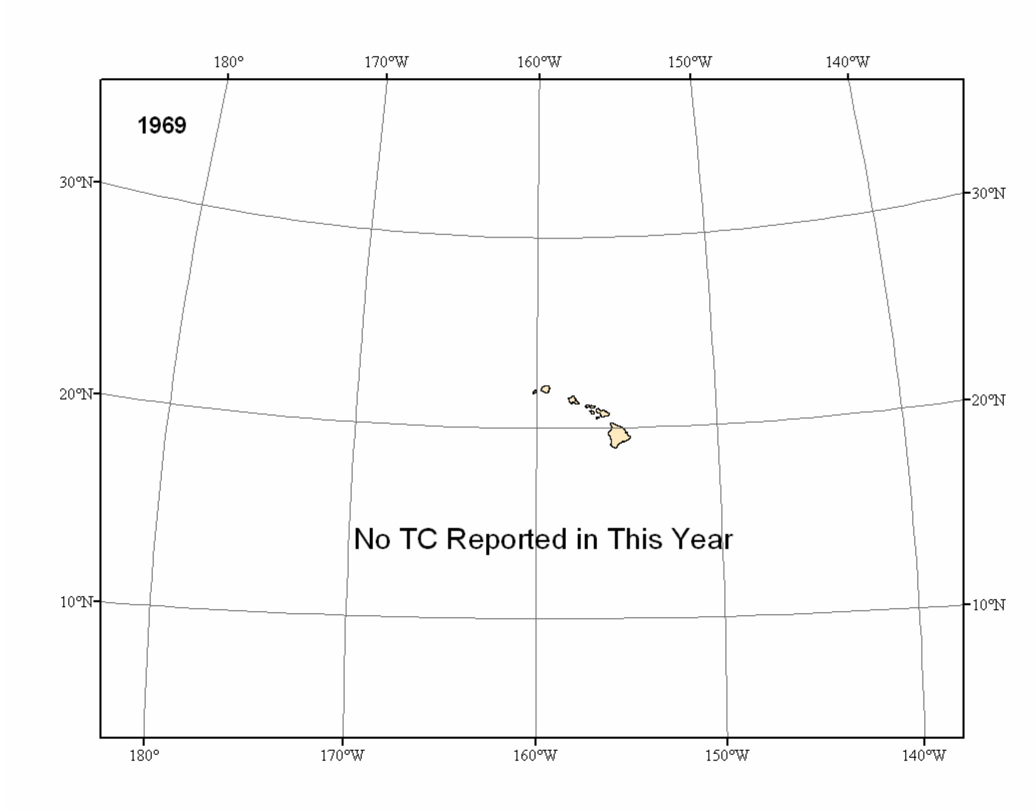

Figure 4.4. TC Tracks for 1969.

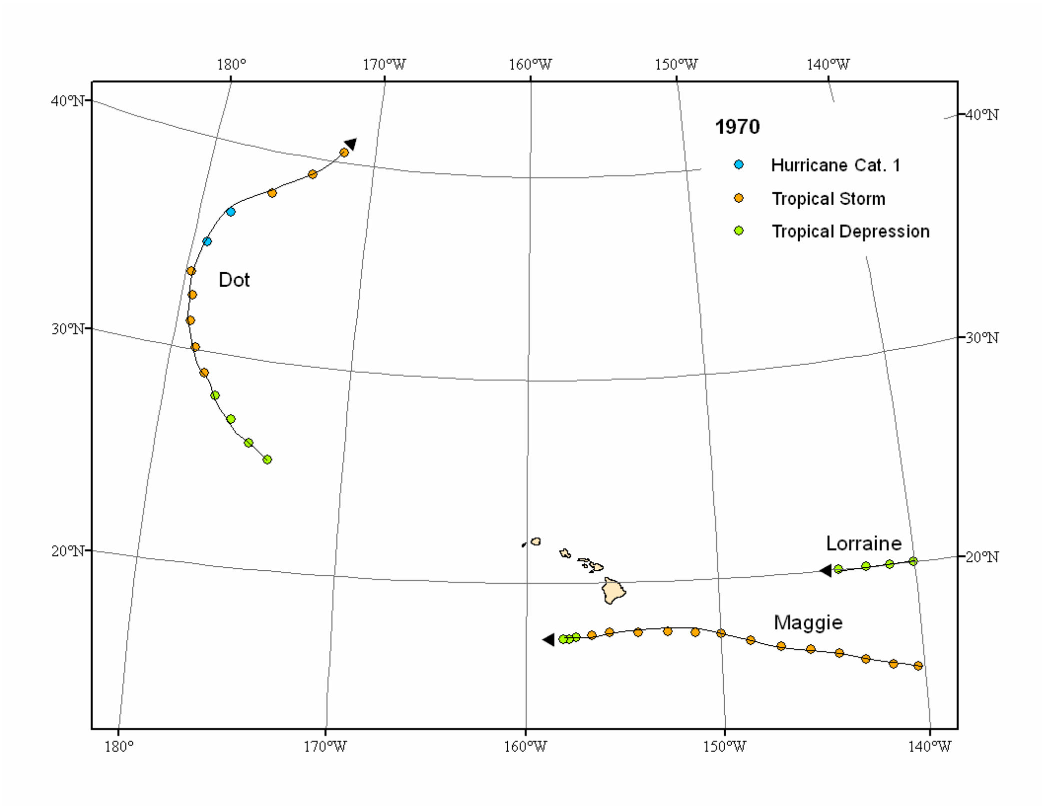

Figure 4.5. TC Tracks for 1970.

Name	Starting Date	Ending Date	Max Wind Speed
Lorraine	8/26	8/27	30
Maggie	8/26	8/27	45
Dot	9/1	9/4	70

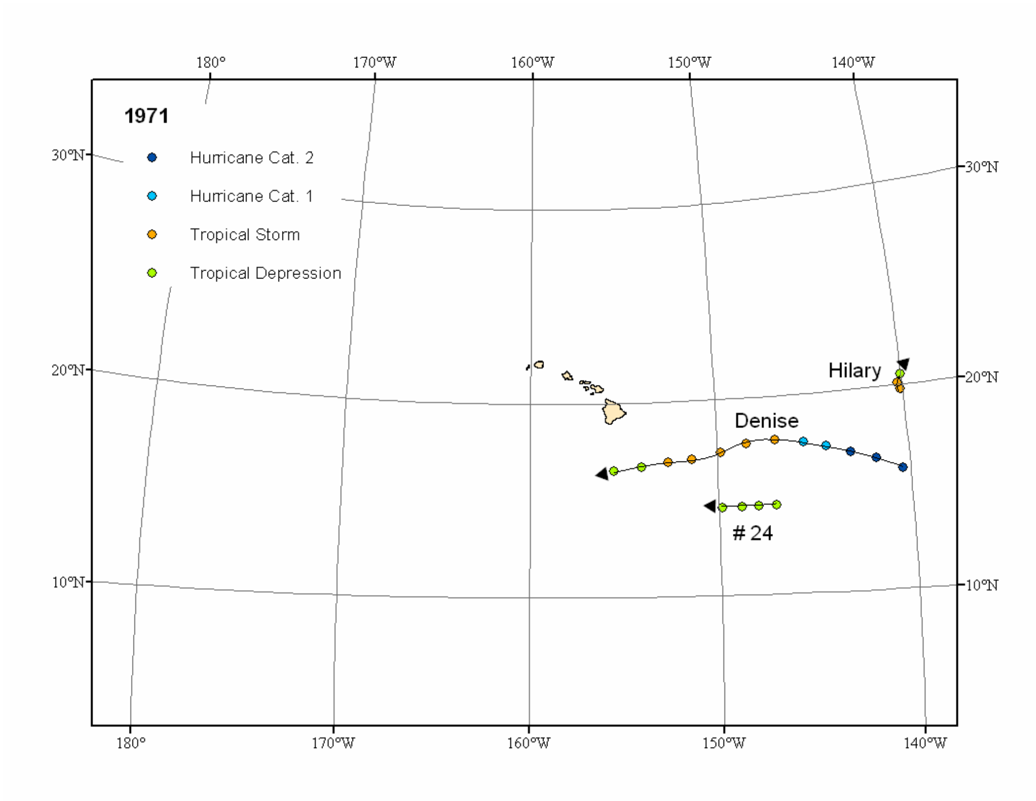

Figure 4.6. TC Tracks for 1971.

Name	Starting Date	Ending Date	Max Wind Speed
Denise	7/11	7/13	95
Hilary	8/6	8/6	35
# 24	8/24	8/24	25

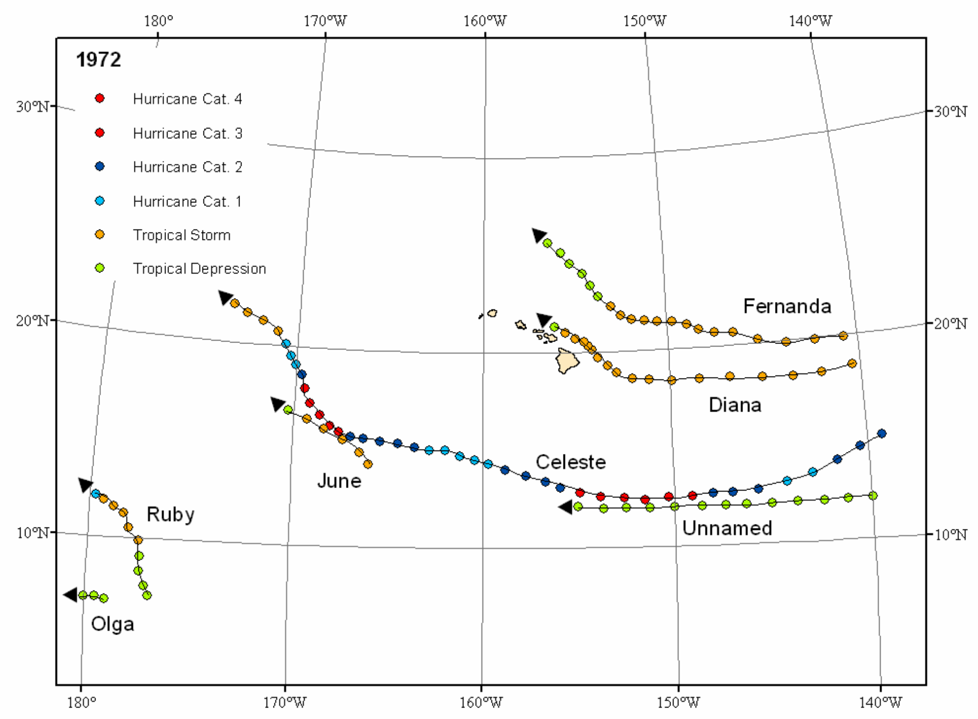

Figure 4.7. TC Tracks for 1972.

Name	Starting Date	Ending Date	Max Wind Speed
Celeste	8/12	8/22	115
Diana	8/16	8/20	55
Fernanda	8/27	8/31	45
June	9/26	9/28	50
Unnamed	9/30	10/3	25
Olga	10/19	10/19	30
Ruby	11/12	11/14	70

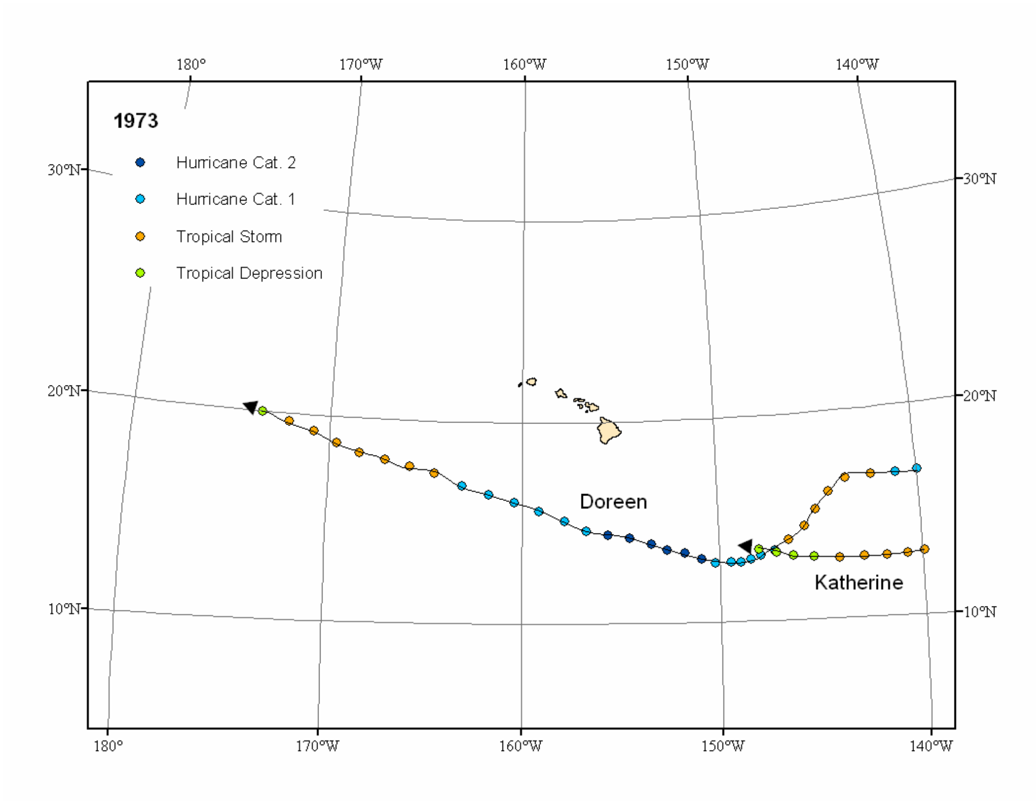

Figure 4.8. TC Tracks for 1973.

Name	Starting Date	Ending Date	Max Wind Speed
Doreen	7/25	8/3	90
Katherine	10/6	10/8	50

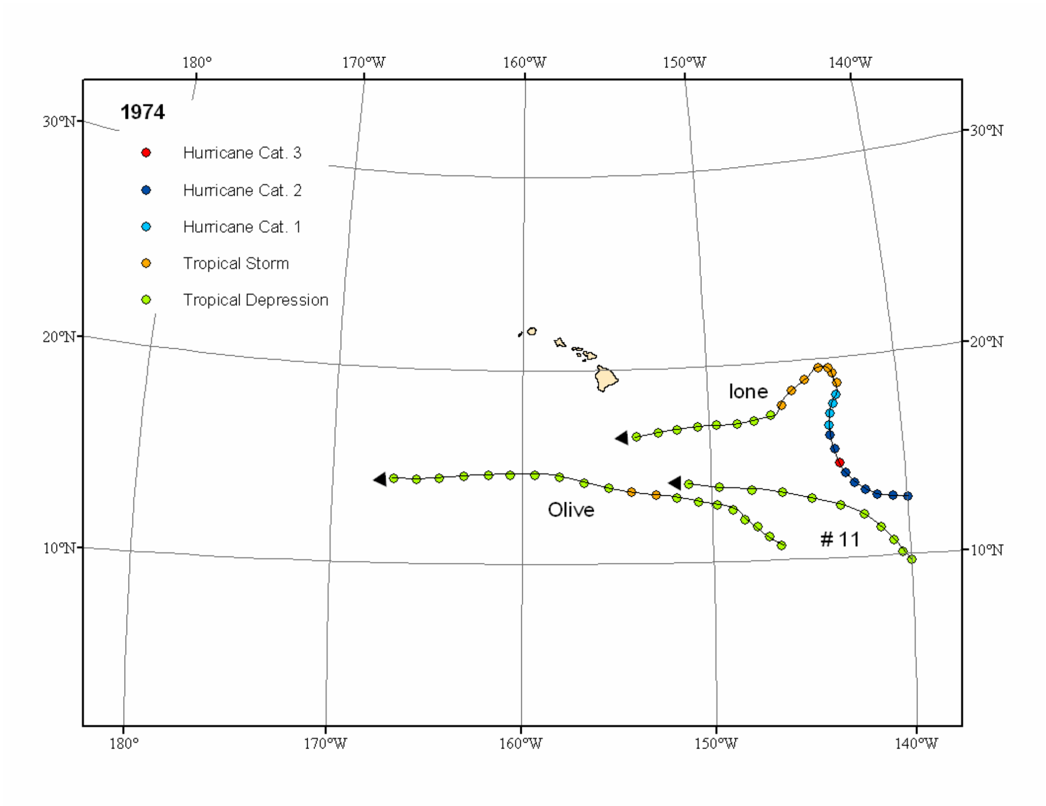

Figure 4.9. TC Tracks for 1974.

Name	Starting Date	Ending Date	Max Wind Speed
# 11	8/9	8/11	25
Olive	8/21	8/26	35
Ione	8/24	8/31	100

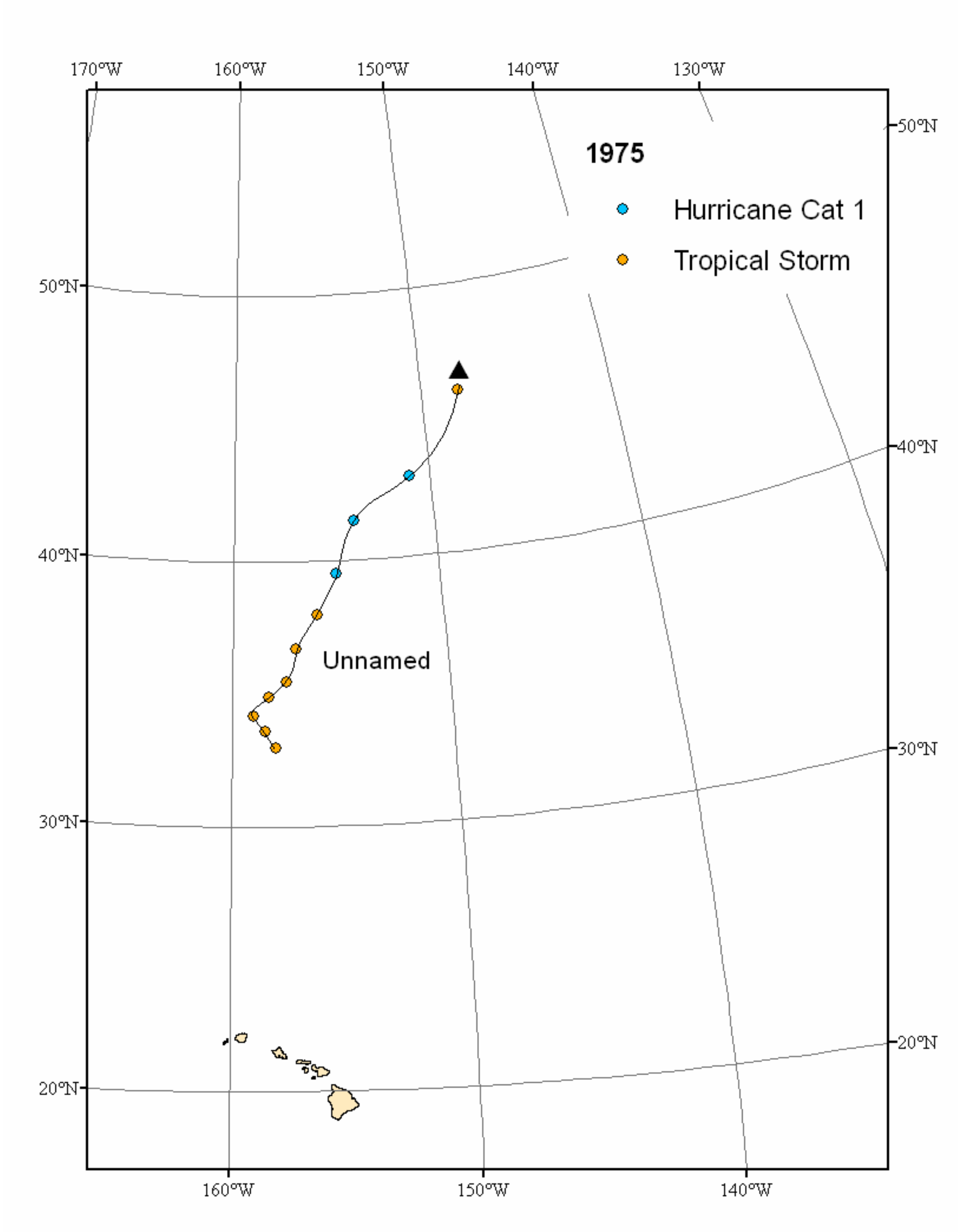

Figure 4.10. TC Tracks for 1975.

Name	Starting Date	Ending Date	Max Wind Speed
Unnamed	8/31	9/5	65

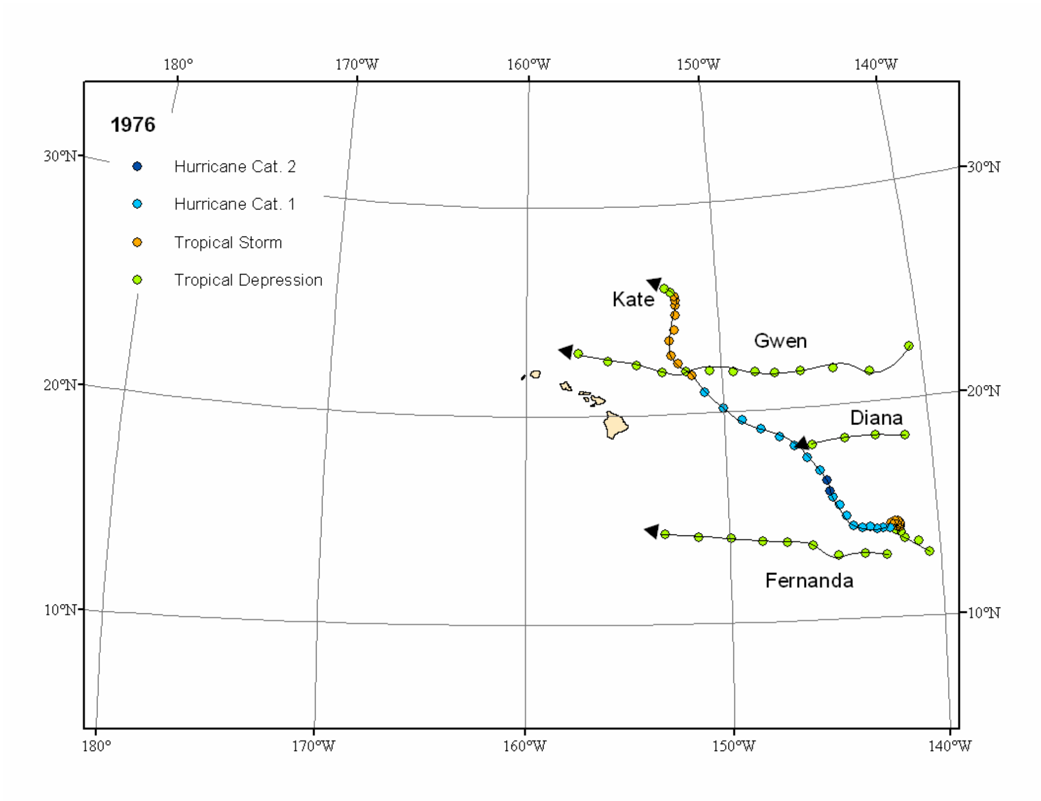

Figure 4.11. TC Tracks for 1976.

Name	Starting Date	Ending Date	Max Wind Speed
Diana	7/22	7/23	30
Fernanda	7/30	8/1	30
Gwen	8/14	8/17	30
Kate	9/21	10/2	85

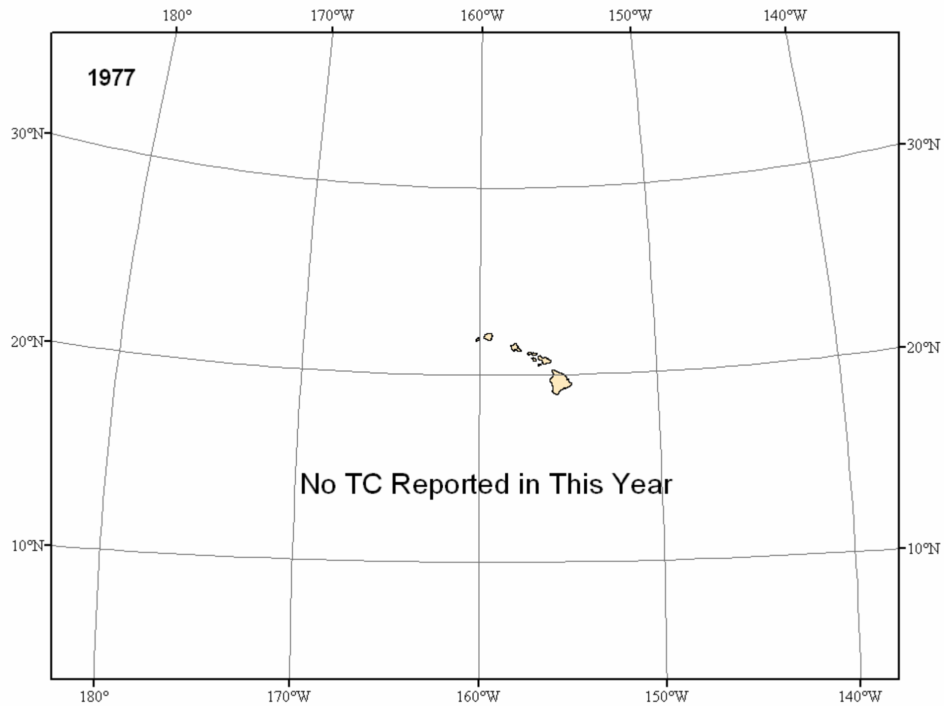

Figure 4.12. TC Tracks for 1977.

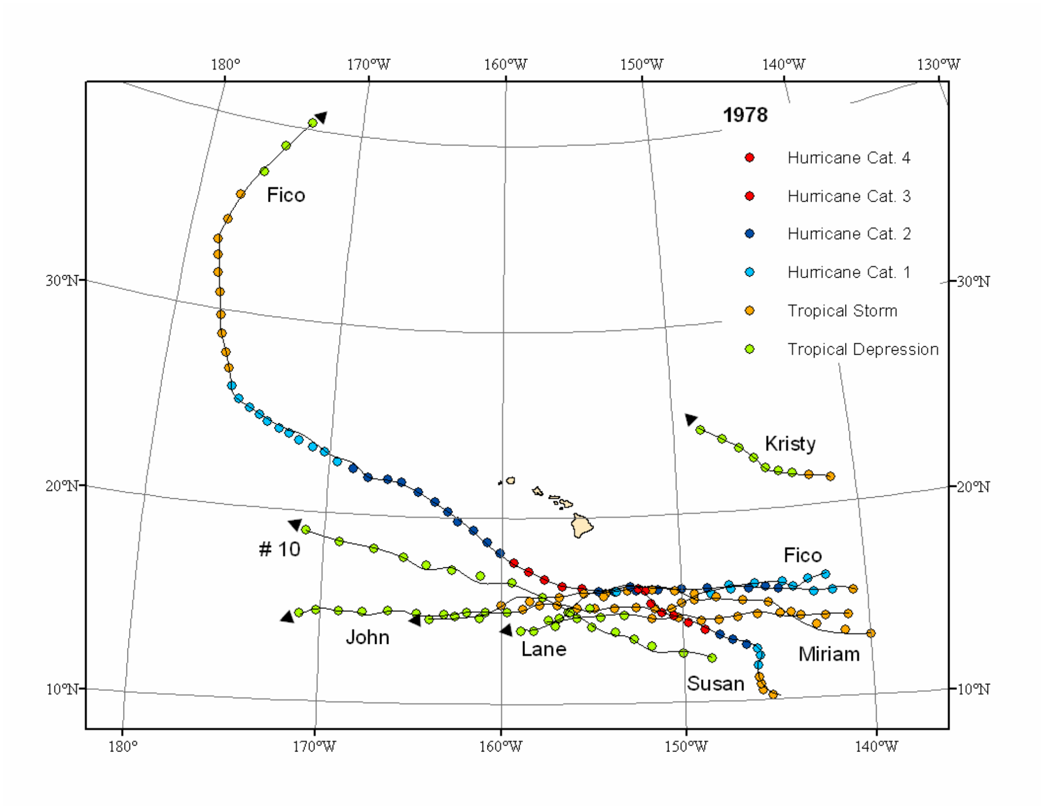

Figure 4.13. TC Tracks for 1978.

Name	Starting Date	Ending Date	Max Wind Speed
Fico	7/18	7/30	100
# 10	8/6	8/9	30
Lane	8/20	8/24	50
John	8/23	8/31	90
Kristy	8/26	8/28	40
Miriam	8/28	9/1	55
Susan	10/18	10/24	115

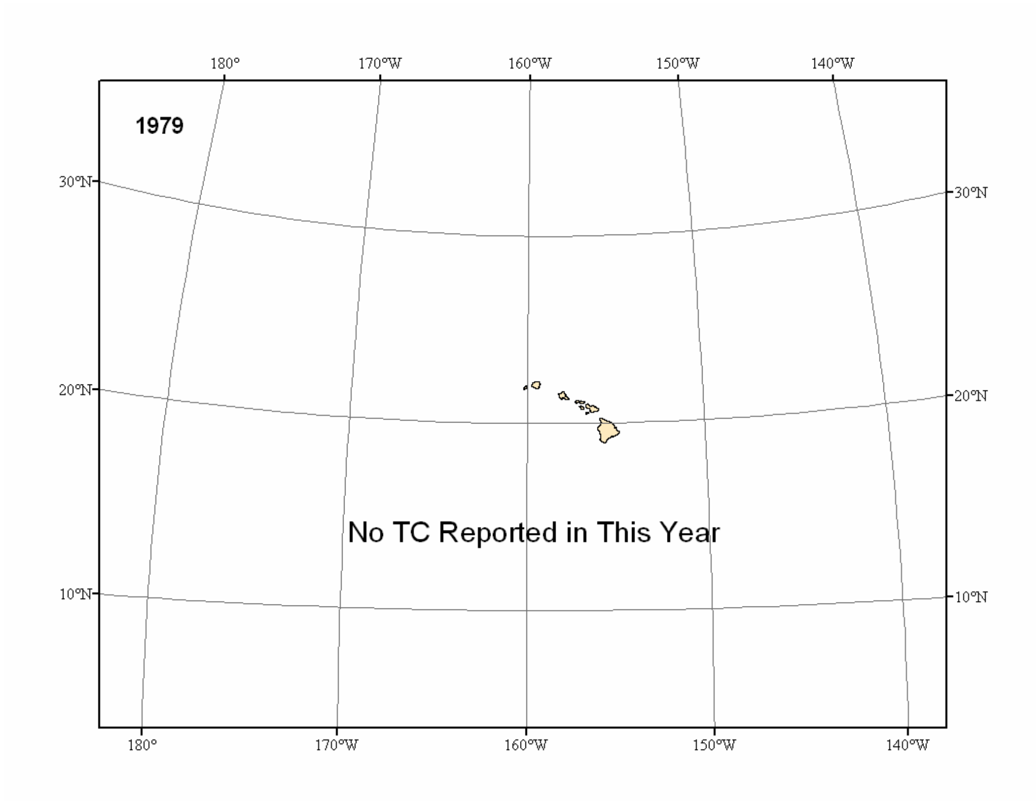

Figure 4.14. TC Tracks for 1979.

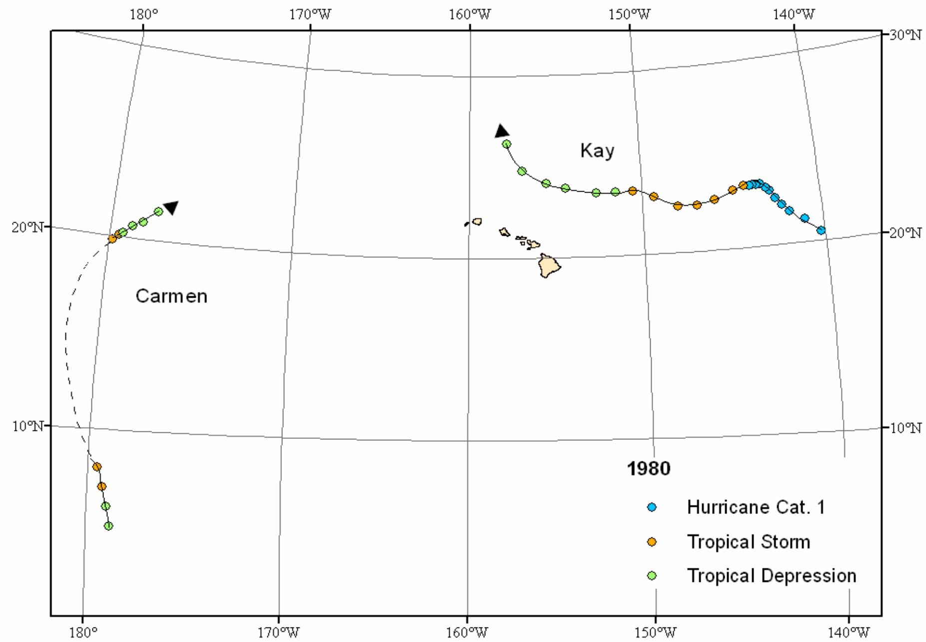

Figure 4.15. TC Tracks for 1980.

Name	Starting Date	Ending Date	Max Wind Speed
Carmen	4/4	4/9	45
Kay	9/24	9/30	75

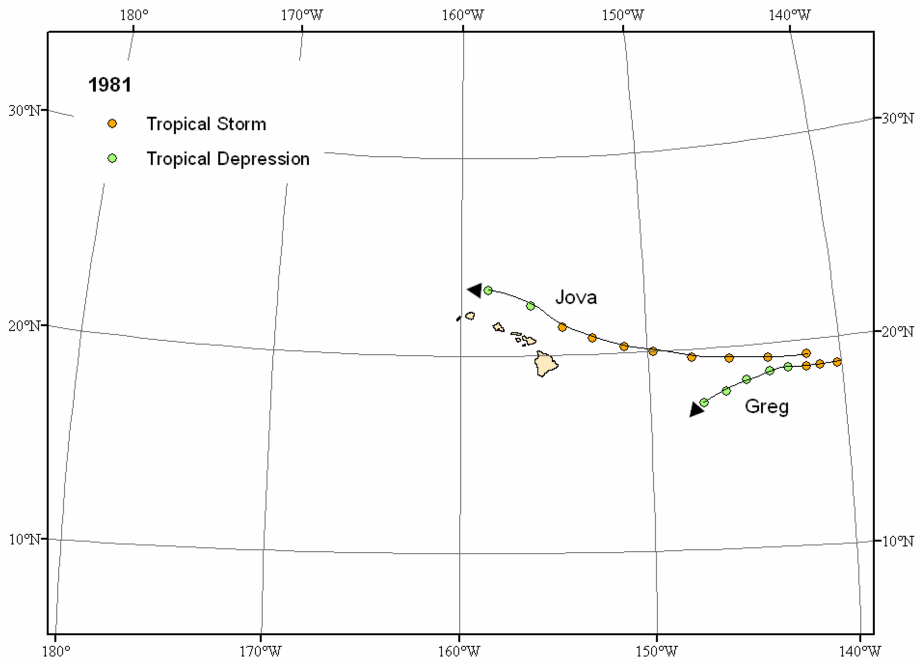

Figure 4.16. TC Tracks for 1981.

Name	Starting Date	Ending Date	Max Wind Speed
Greg	8/21	8/22	45
Jova	9/18	9/21	50

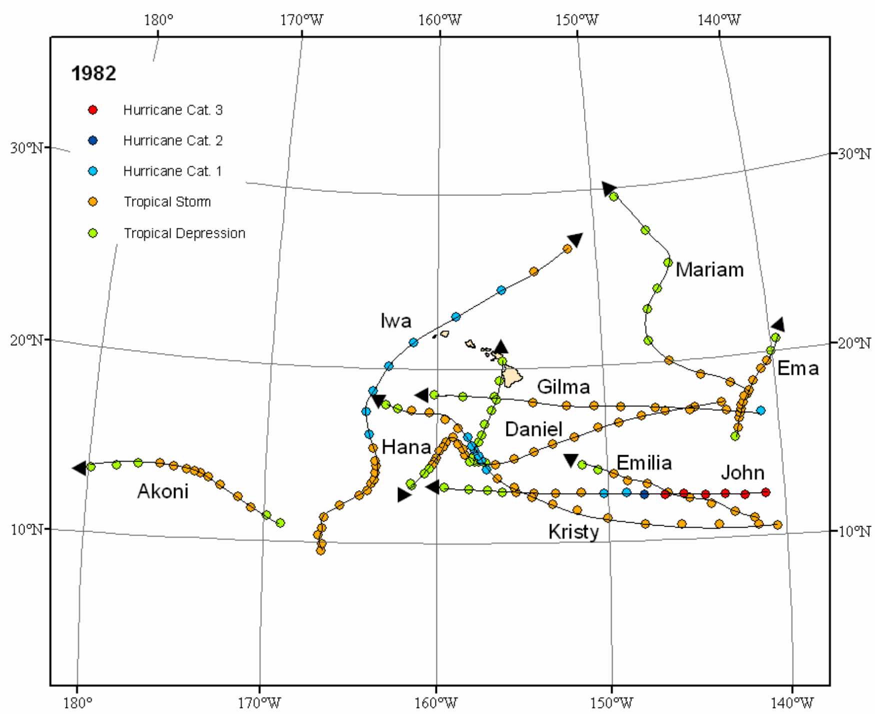

Figure 4.17. TC Tracks for 1982.

Name	Starting Date	Ending Date	Max Wind Speed
Emilia	7/13	7/15	55
Daniel	7/16	7/22	40
Gilma	7/30	8/2	75
John	8/6	8/11	100
Kristy	8/11	8/17	80
Akoni	8/30	9/2	45
Miriam	9/4	9/6	45
Ema	9/15	9/19	40
Hana	9/15	9/19	35
Iwa	11/19	11/25	80

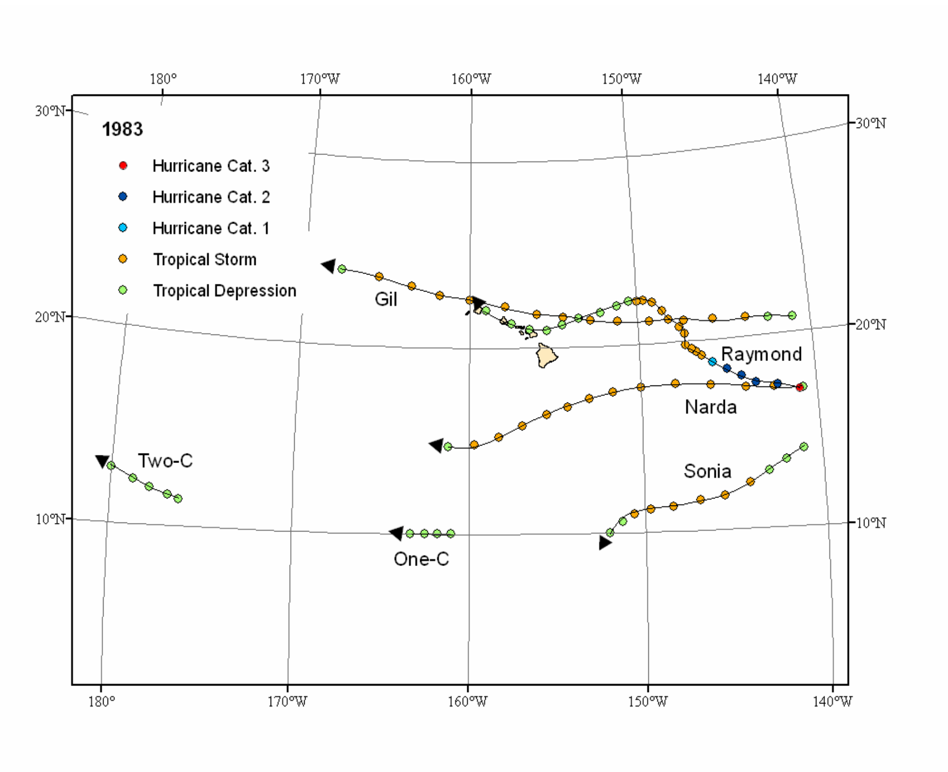

Figure 4.18. TC Tracks for 1983.

Name	Starting Date	Ending Date	Max Wind Speed
Gil	8/1	8/5	40
One-C	8/1	8/1	30
Two-C	8/31	9/1	30
Narda	9/27	10/1	60
Sonia	10/12	10/14	40
Raymond	10/14	10/20	110

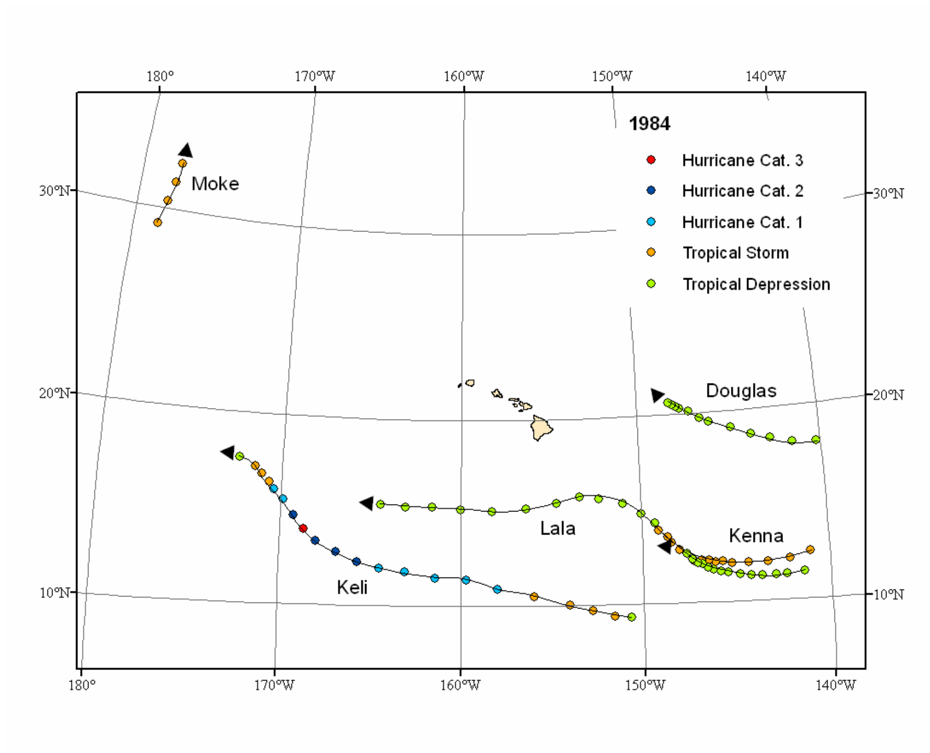

Figure 4.19. TC Tracks for 1984.

Name	Starting Date	Ending Date	Max Wind Speed
Douglas	7/3	7/6	1/30
Keli	8/16	8/21	4/9
Kenna	8/18	8/20	2/19
Lala	8/26	9/2	2/9
Moke	9/3	9/5	2/14

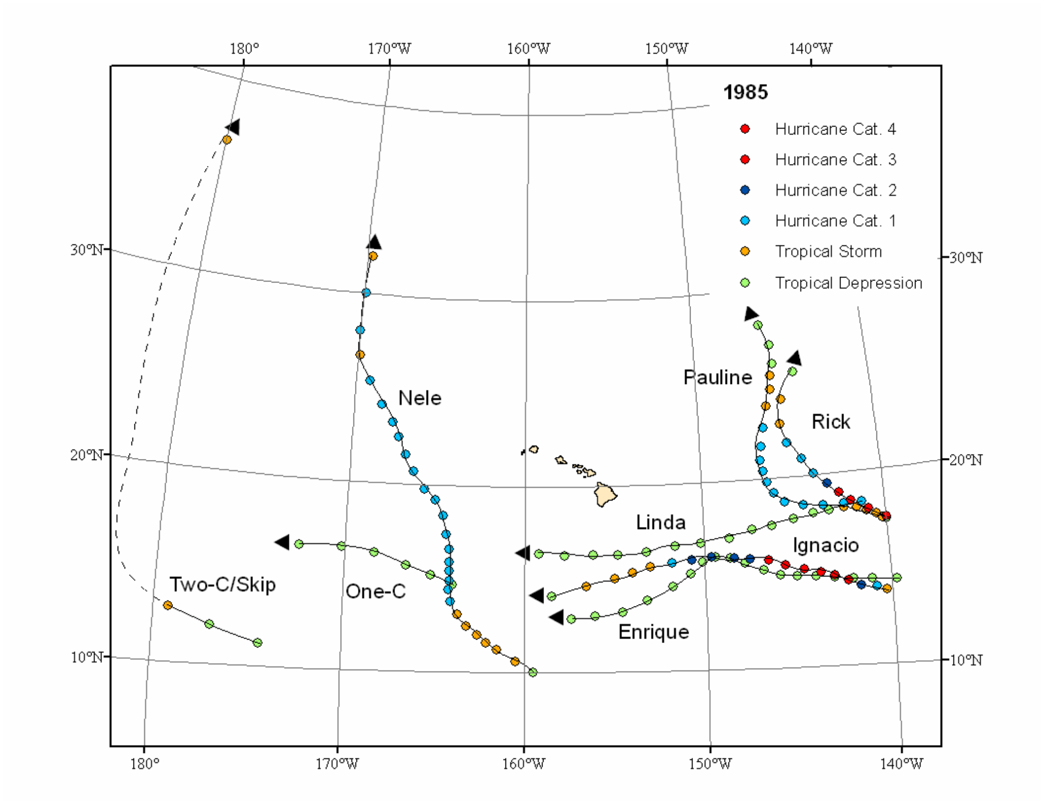

Figure 4.20. TC Tracks for 1985.

Name	Starting Date	Ending Date	Max Wind Speed
Enrique	7/1	7/5	25
Ignacio	7/22	7/27	115
Linda	8/4	8/9	40
One-C	8/20	8/22	30
Two-C/Skip	8/30	9/8	60
Pauline	9/5	9/9	75
Rick	9/9	9/12	125
Nele	10/23	10/30	80

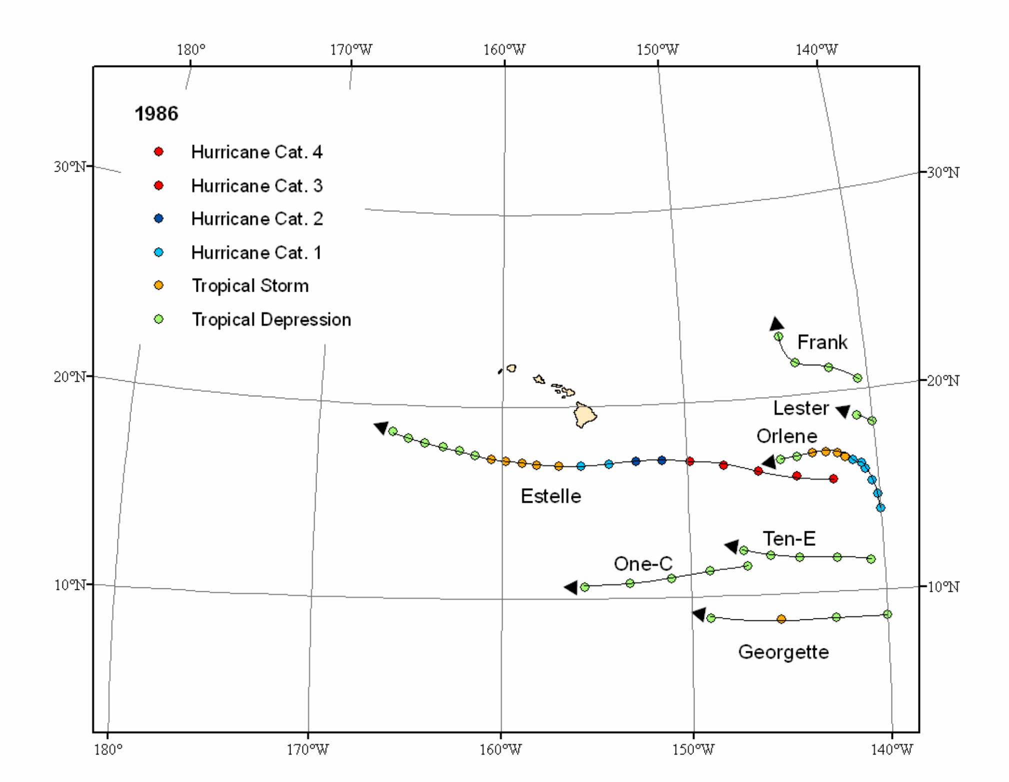

Figure 4.21. TC Tracks for 1986.

Name	Starting Date	Ending Date	Max Wind Speed
Estelle	7/21	7/26	115
One-C	7/28	7/29	30
Ten-E	7/29	7/30	30
Frank	8/2	8/3	30
Georgette	8/4	8/8	35
Lester	9/16	9/17	30
Orlene	9/22	9/25	70

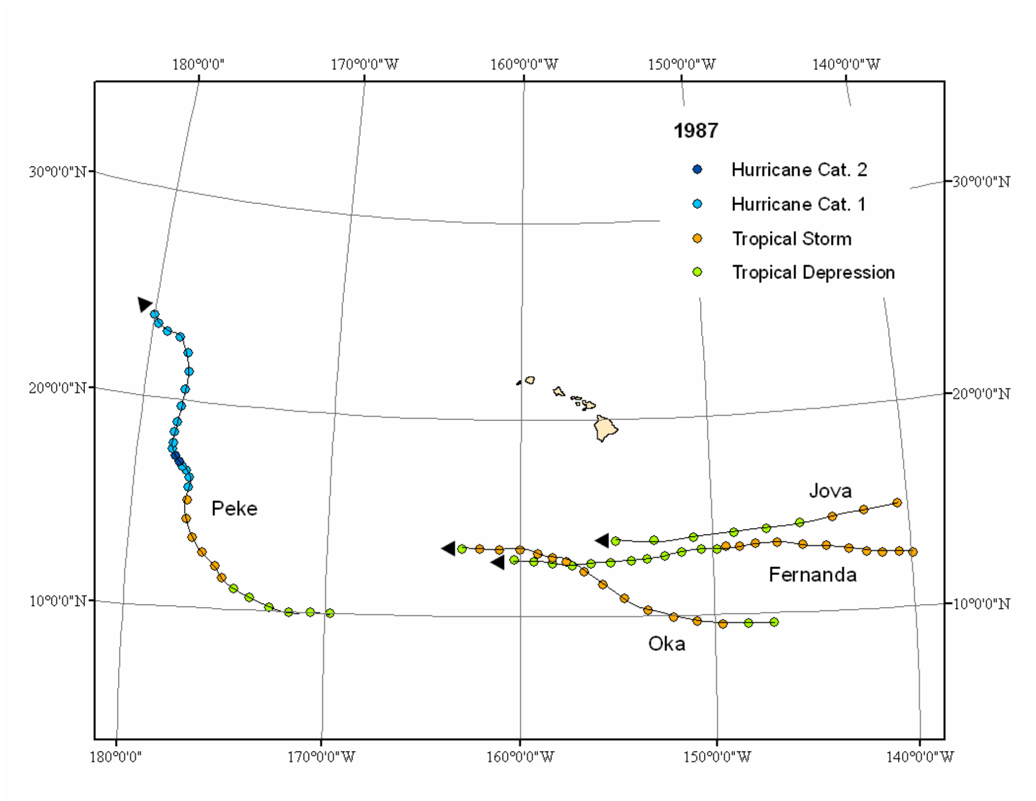

Figure 4.22. TC Tracks for 1987.

Name	Starting Date	Ending Date	Max Wind Speed
Fernanda	7/26	7/31	55
Jova	8/20	8/22	45
Oka	8/26	8/29	50
Peke	9/21	9/28	85

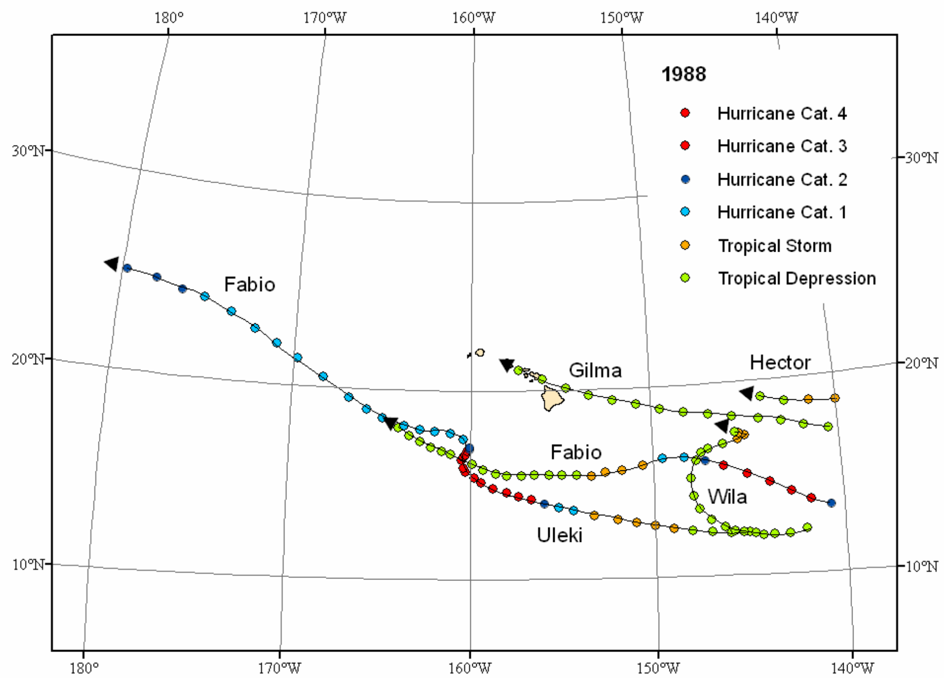

Figure 4.23. TC Tracks for 1988.

Name	Starting Date	Ending Date	Max Wind Speed
Gilma	7/31	8/3	25
Fabio	8/2	8/9	120
Hector	8/9	8/9	40
Uleki	8/28	9/8	105
Wila	9/21	9/25	35

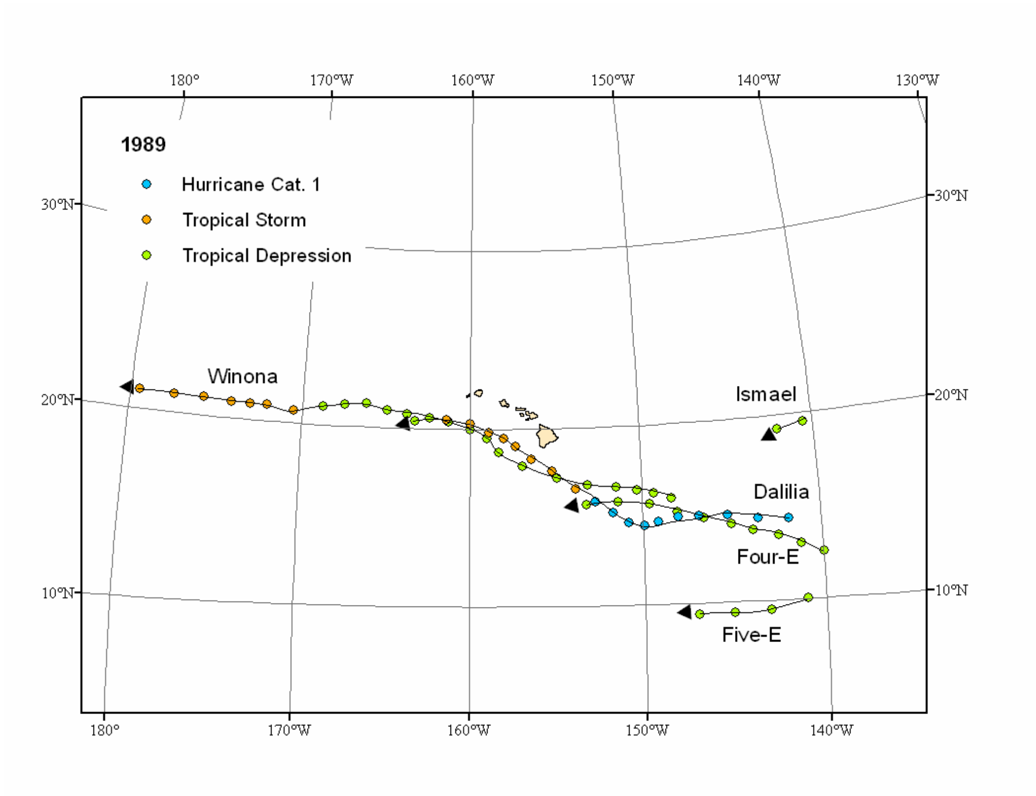

Figure 4.24. TC Tracks for 1989.

Name	Starting Date	Ending Date	Max Wind Speed
Winona	1/9	1/15	40
Four-E	7/11	7/13	30
Five-E	7/14	7/14	30
Dalilia	7/17	7/21	65
Ismael	8/25	8/25	20

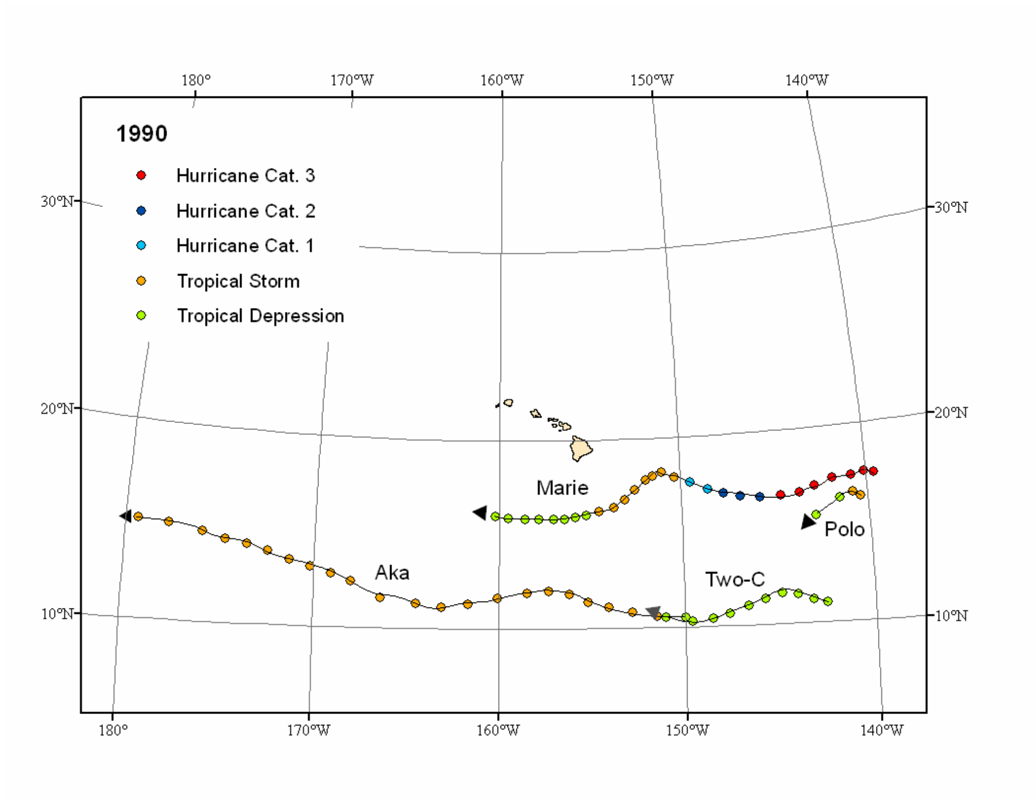

Figure 4.25. TC Tracks for 1990.

Name	Starting Date	Ending Date	Max Wind Speed
Aka	8/7	8/13	55
Two-C	8/10	8/13	30
Marie	9/14	9/21	100
Polo	10/1	10/1	50

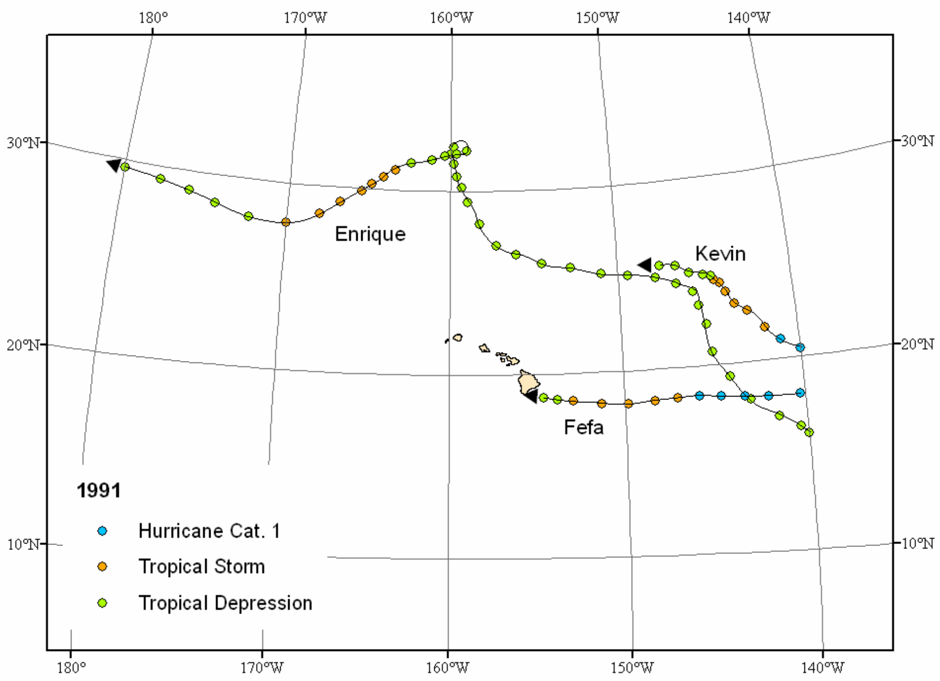

Figure 4.26. TC Tracks for 1991.

Name	Starting Date	Ending Date	Max Wind Speed
Enrique	7/21	7/31	45
Fefa	8/5	8/8	85
Kevin	10/9	10/12	75

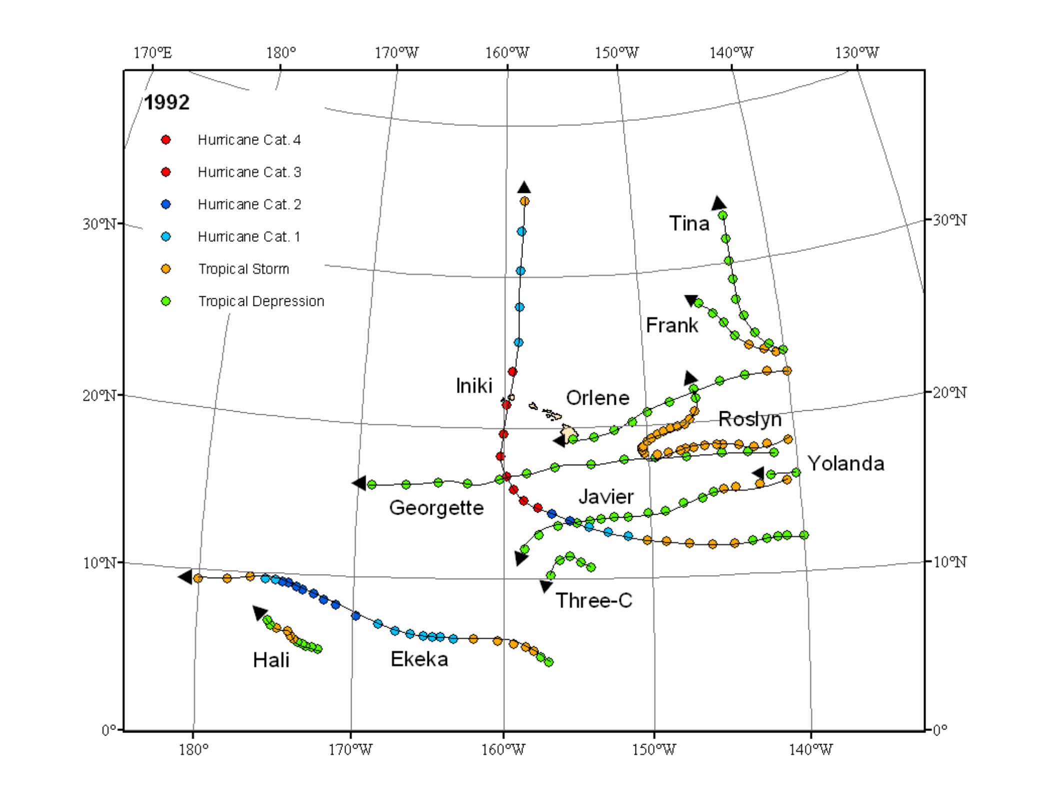

Figure 4.27. TC Tracks for 1992.

Name	Starting Date	Ending Date	Max Wind Speed
Ekeka	1/28	2/3	100
Hali	3/28	3/30	40
Frank	7/22	7/23	45
Georgette	7/24	7/27	30
Javier	8/8	8/12	40
Iniki	9/6	9/13	125
Orlene	9/12	9/14	40
Roslyn	9/24	9/30	60
Tina	10/9	10/11	30
Yolanda	10/12	10/12	25
Three-C	11/22	11/23	30

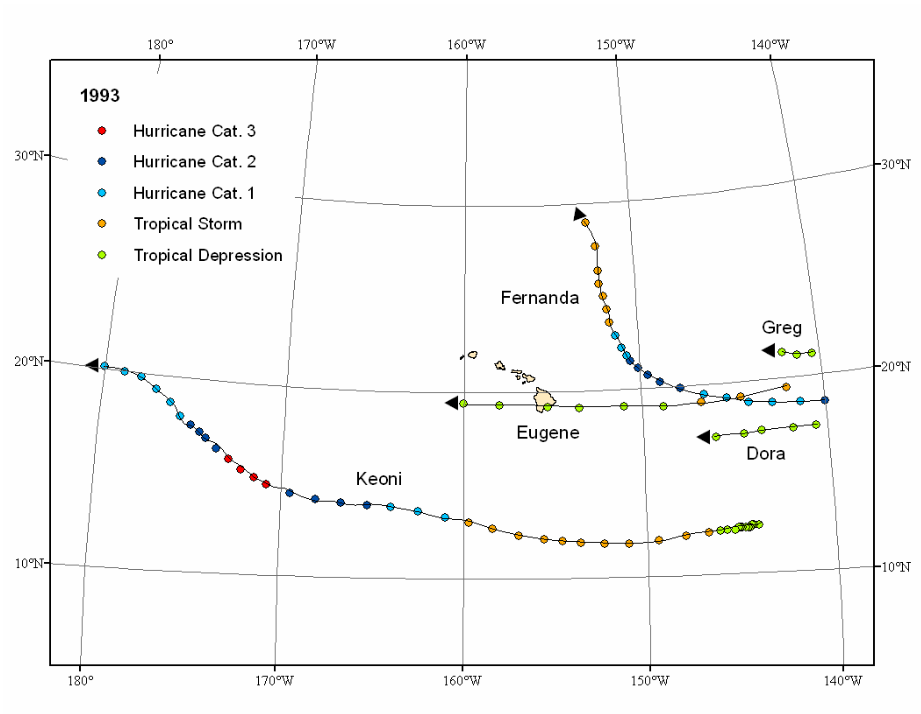

Figure 4.28. TC Tracks for 1993.

Name	Starting Date	Ending Date	Max Wind Speed
Dora	7/20	7/21	25
Eugene	7/23	7/25	35
Keoni	8/9	8/19	115
Fernanda	8/14	8/19	90
Greg	8/28	8/28	30

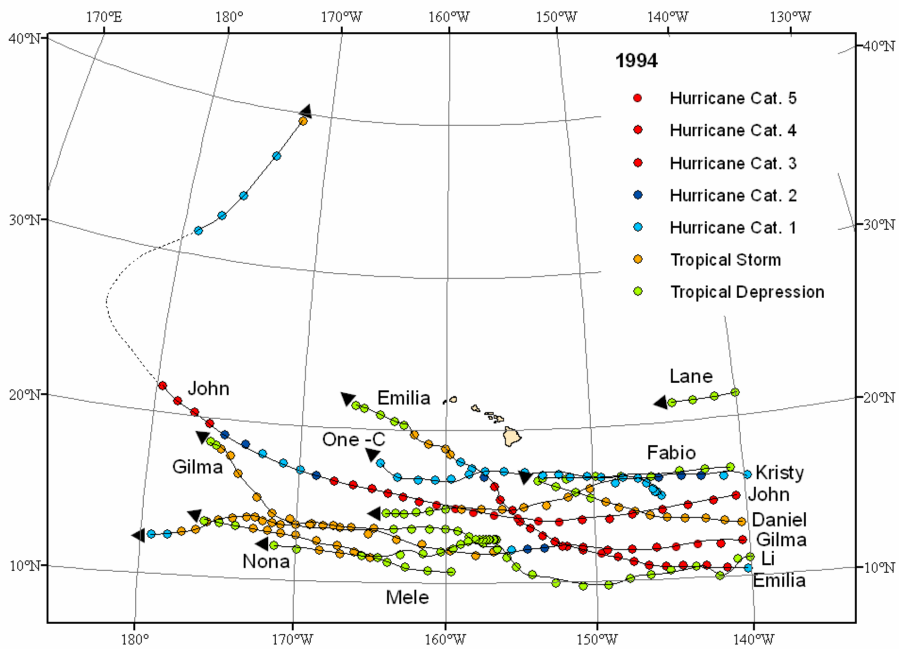

Figure 4.29. TC Tracks for 1994.

Name	Starting Date	Ending Date	Max Wind Speed
Daniel	7/11	7/14	55
Emilia	7/17	7/25	140
Fabio	7/22	7/24	25
Gilma	7/24	7/31	140
Li	8/3	8/12	65
One-C	8/9	8/14	30
John	8/21	9/10	150
Kristy	8/31	9/5	90
Mele	9/6	9/9	35
Lane	9/6	9/6	25
Nona	10/21	10/26	35

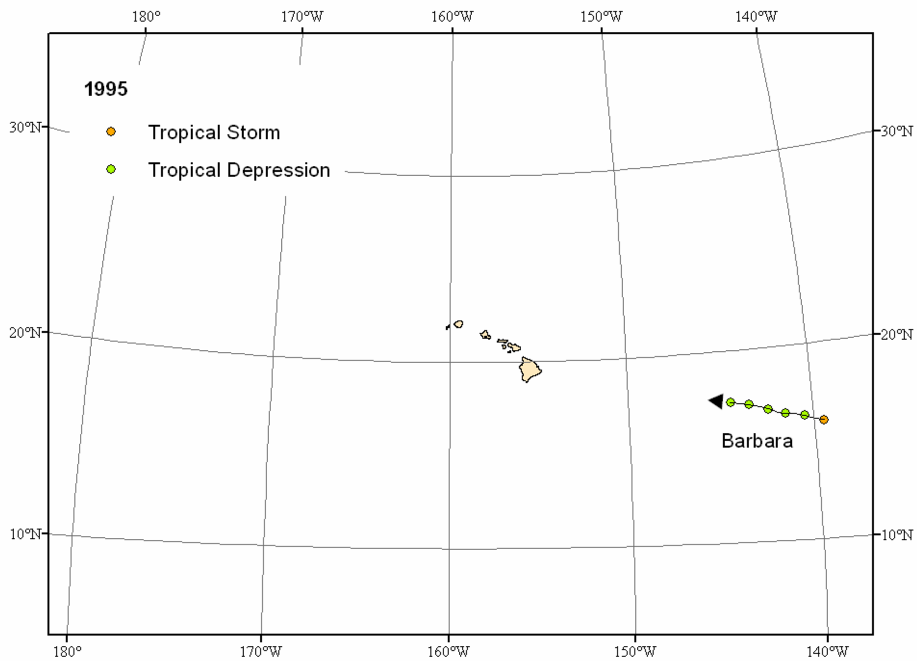

Figure 4.30. TC Tracks for 1995.

Name	Starting Date	Ending Date	Max Wind Speed
Barbara	7/16	7/18	40

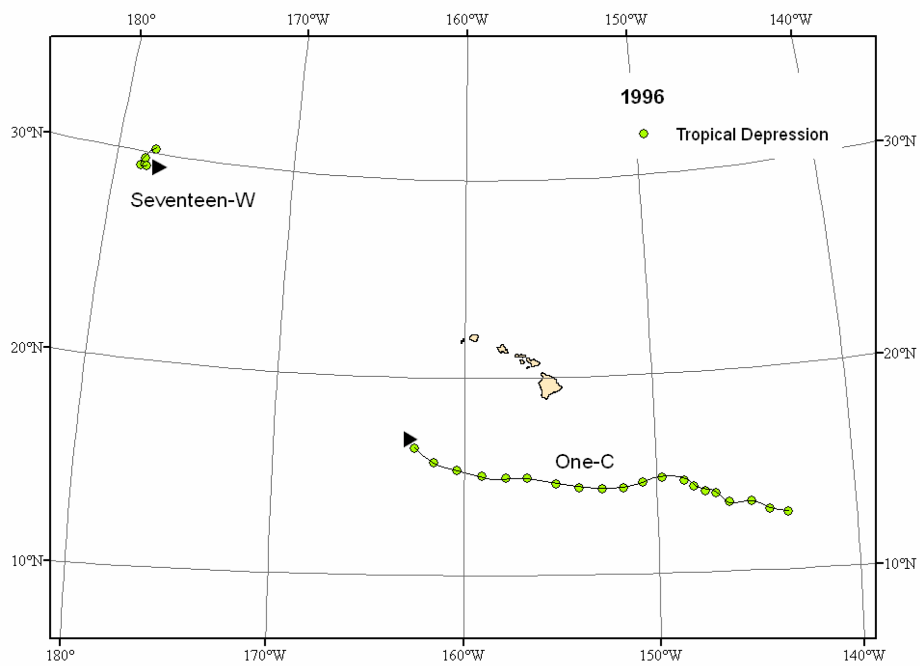

Figure 4.31. TC Tracks for 1996.

Name	Starting Date	Ending Date	Max Wind Speed
Seventeen-W	8/14	8/15	30
One-C	9/16	9/20	30

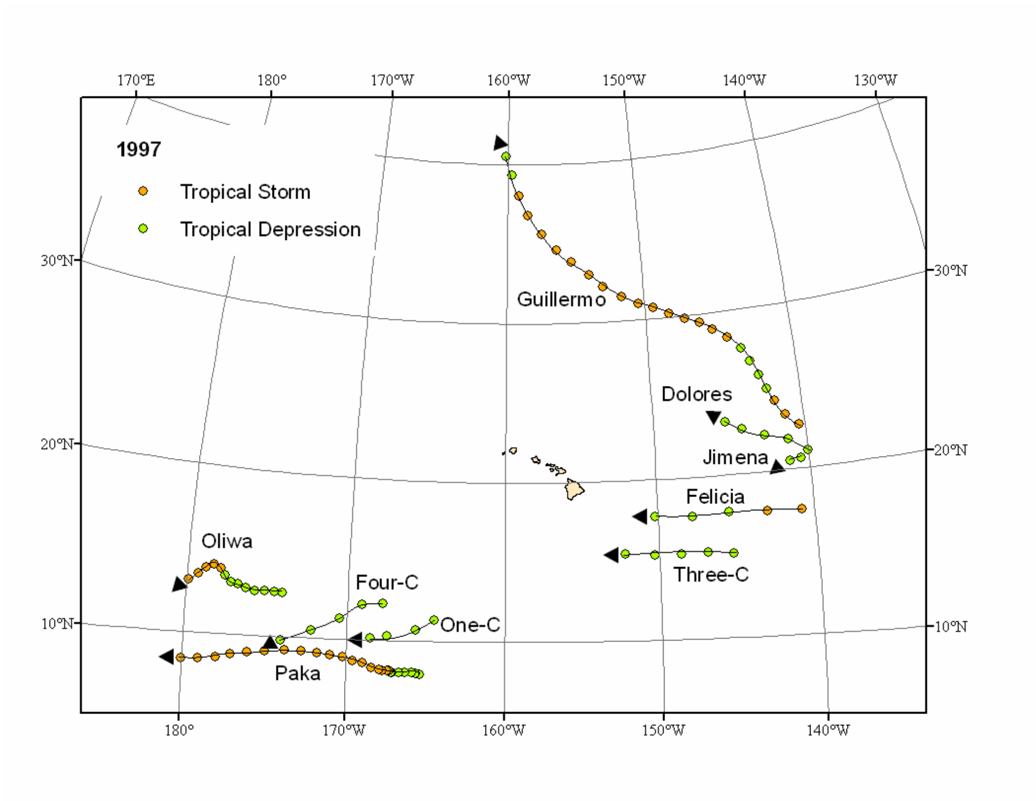

Figure 4.32. TC Tracks for 1997.

Name	Starting Date	Ending Date	Max Wind Speed
Dolores	7/11	7/12	30
Felicia	7/21	7/22	50
One-C	7/27	7/27	25
Guillermo	8/10	8/15	55
Jimena	8/29	8/30	30
Oliwa	9/1	9/4	45
Three-C	10/6	10/7	25
Four-C	10/31	11/1	30
Paka	12/1	12/7	55

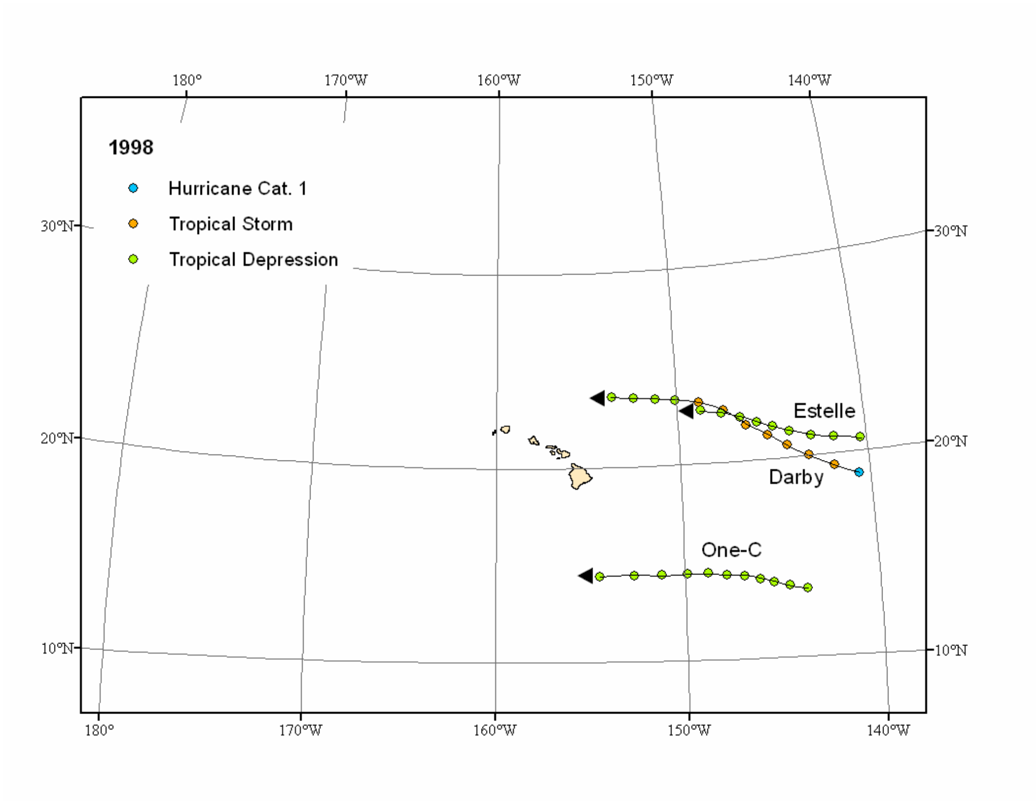

Figure 4.33. TC Tracks for 1998.

Name	Starting Date	Ending Date	Max Wind Speed
Darby	7/29	8/1	65
Estelle	8/6	8/8	30
One-C	8/16	8/19	30

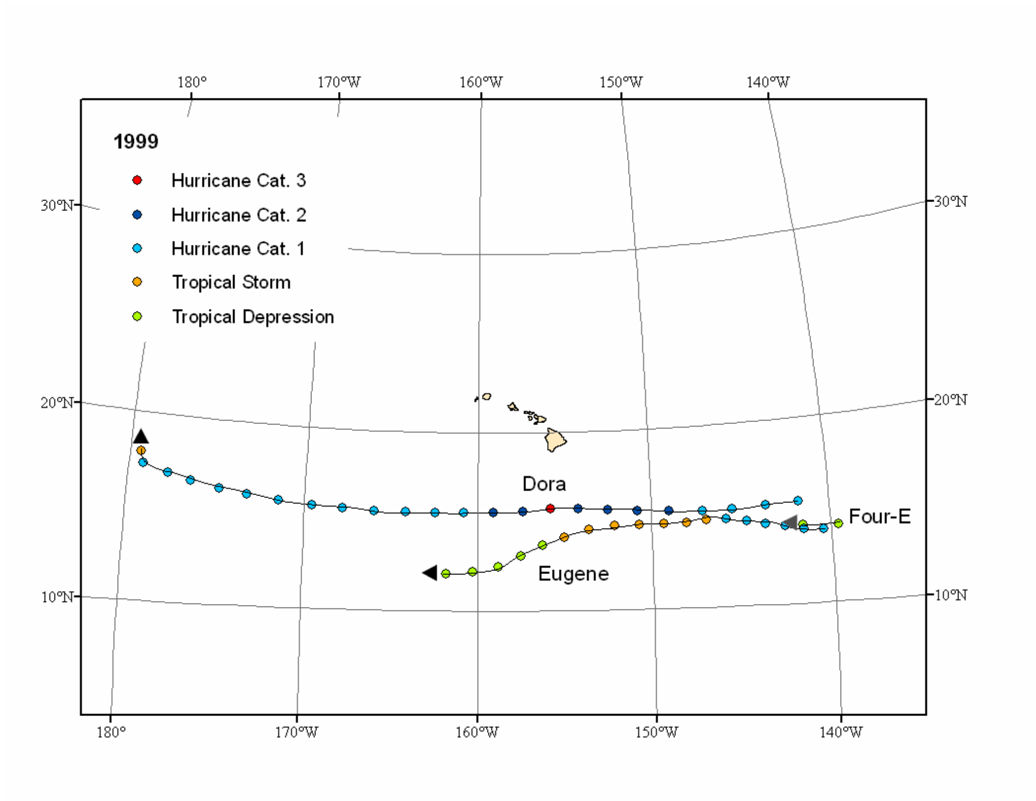

Figure 4.34. TC Tracks for 1999.

Name	Starting Date	Ending Date	Max Wind Speed
Four-E	7/24	7/24	30
Eugene	8/11	8/15	75
Dora	8/14	8/20	100

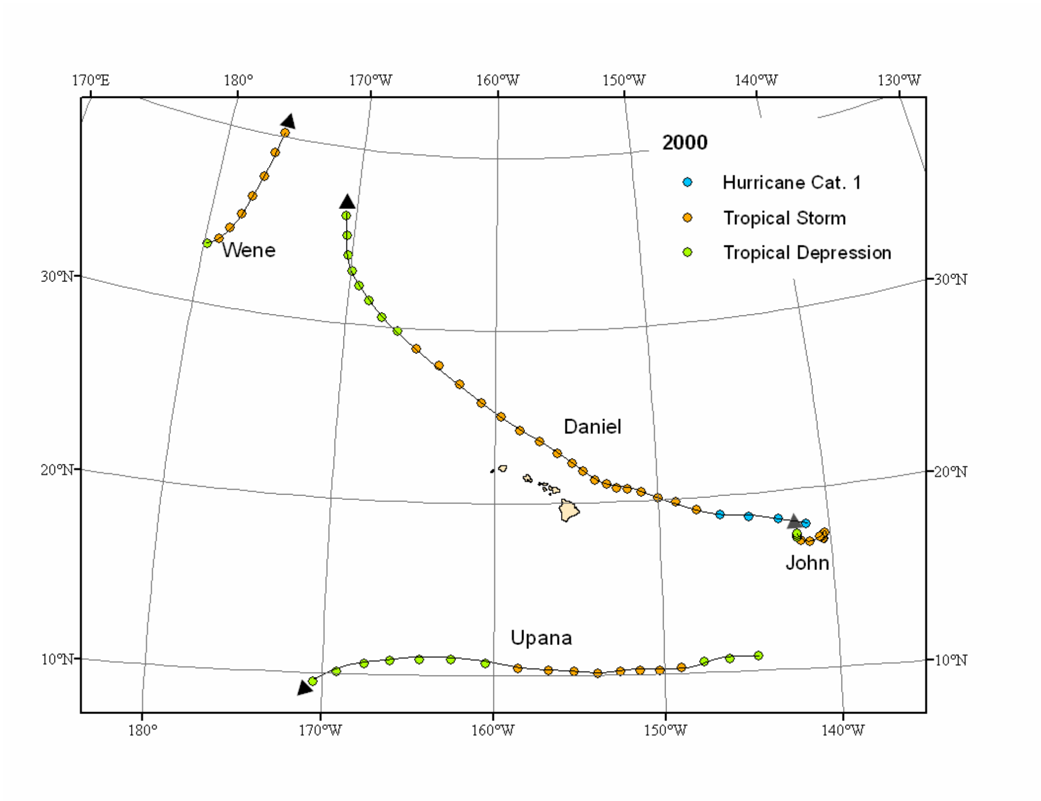

Figure 4.35. TC Tracks for 2000.

Name	Starting Date	Ending Date	Max Wind Speed
Upana	7/20	7/24	40
Daniel	7/29	8/5	80
Wene	8/15	8/17	50
John	8/30	9/1	60

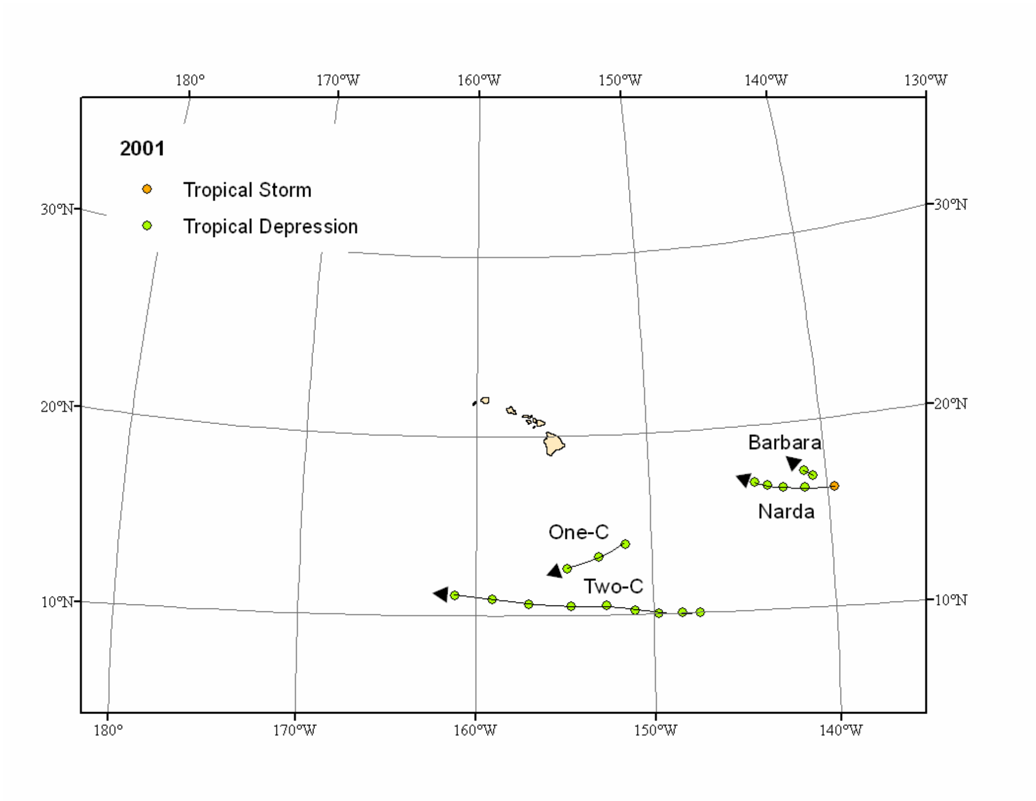

Figure 4.36. TC Tracks for 2001.

Name	Starting Date	Ending Date	Max Wind Speed
Barbara	6/22	6/23	30
One-C	9/11	9/11	30
Two-C	9/23	9/25	30
Narda	10/23	10/24	35

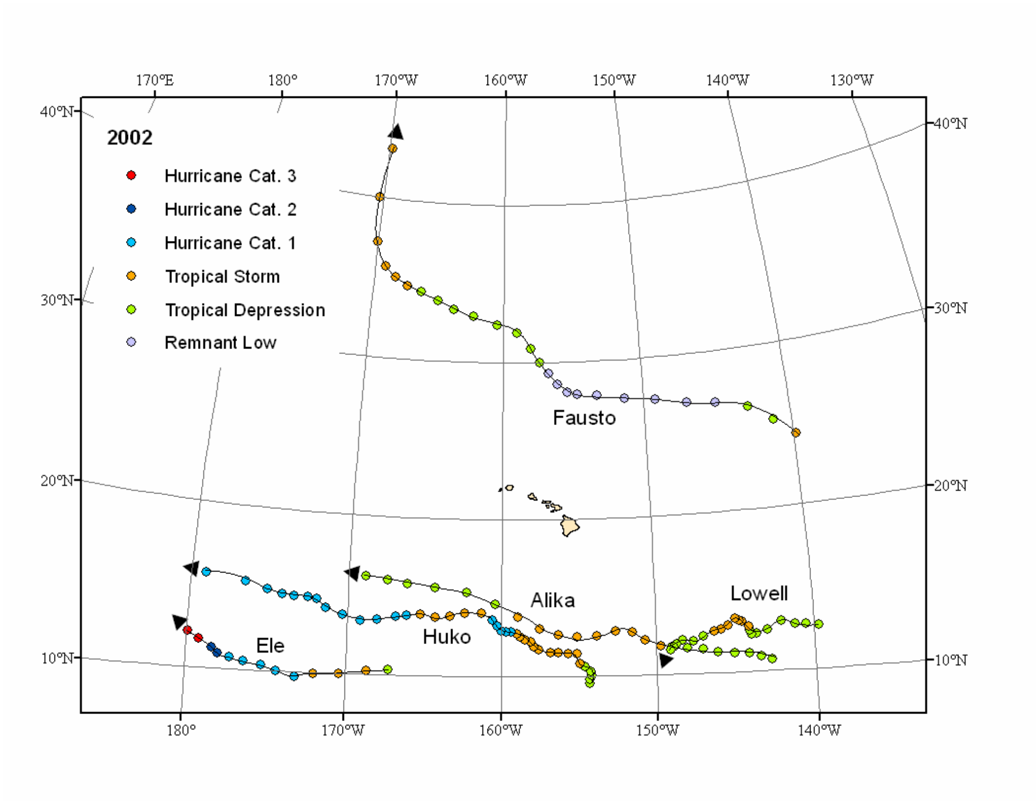

Figure 4.37. TC Tracks for 2002.

Name	Starting Date	Ending Date	Max Wind Speed
Alika	8/22	8/28	55
Ele	8/27	8/30	110
Fausto	8/27	9/3	35
Huko	10/24	11/3	75
Lowell	10/25	10/31	45

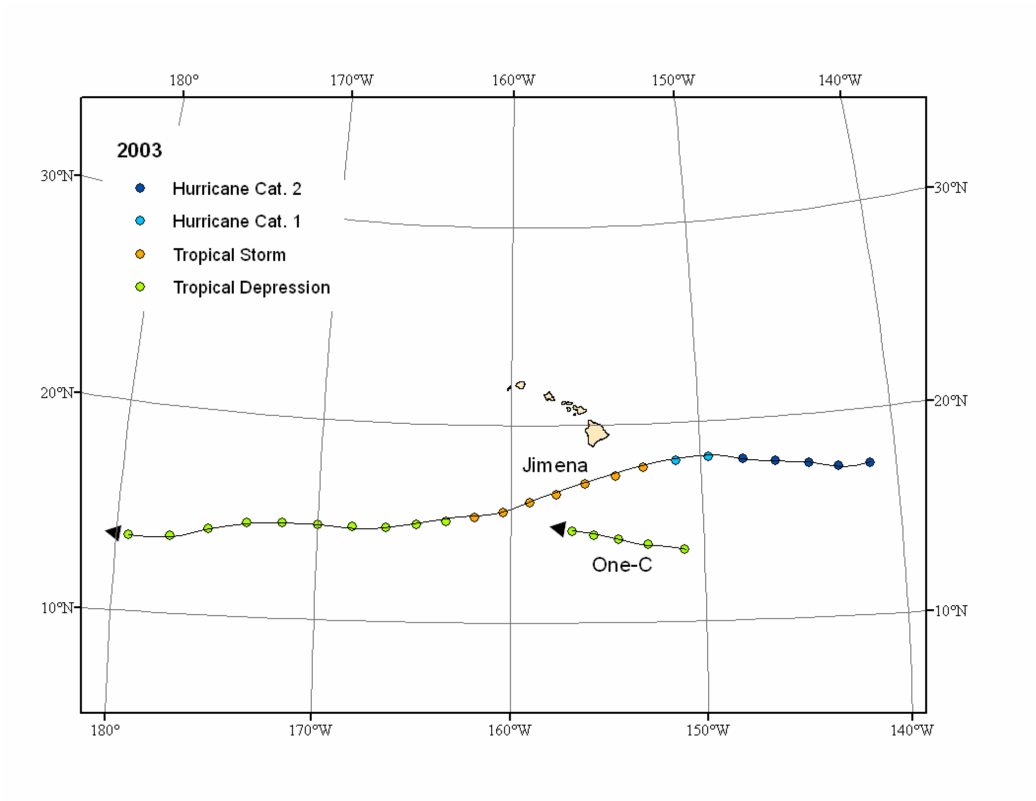

Figure 4.38. TC Tracks for 2003.

Name	Starting Date	Ending Date	Max Wind Speed
One-C	8/15	8/17	30
Jimena	8/30	9/5	90

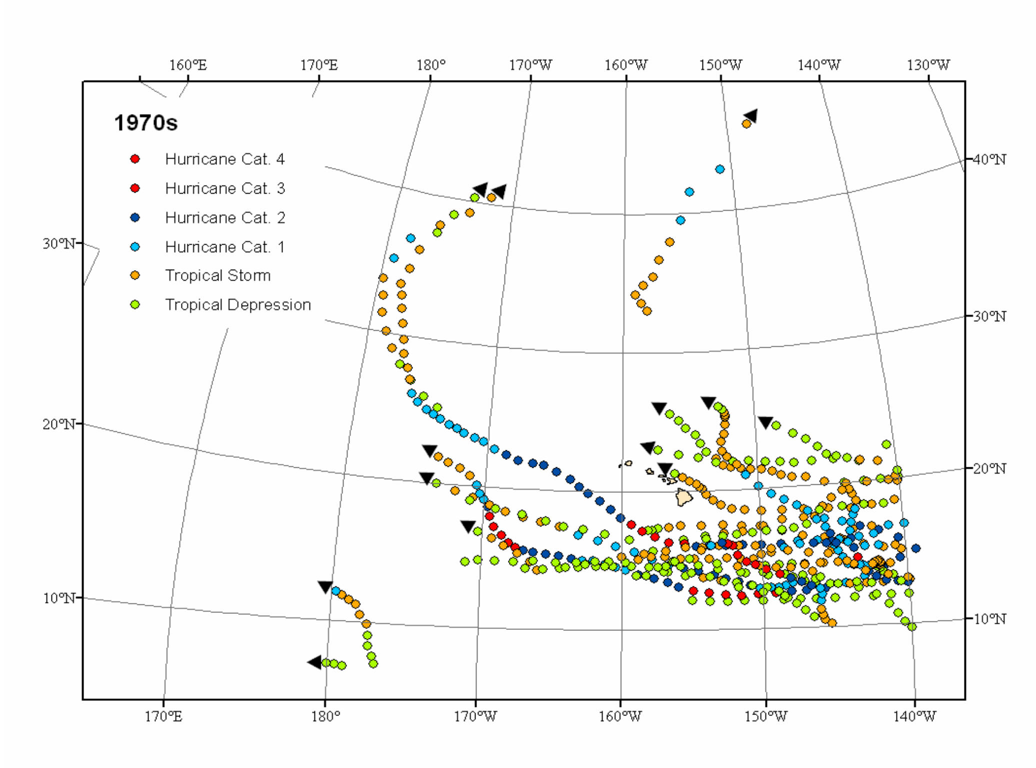

Figure 4.39. TC Tracks for the 1970s.

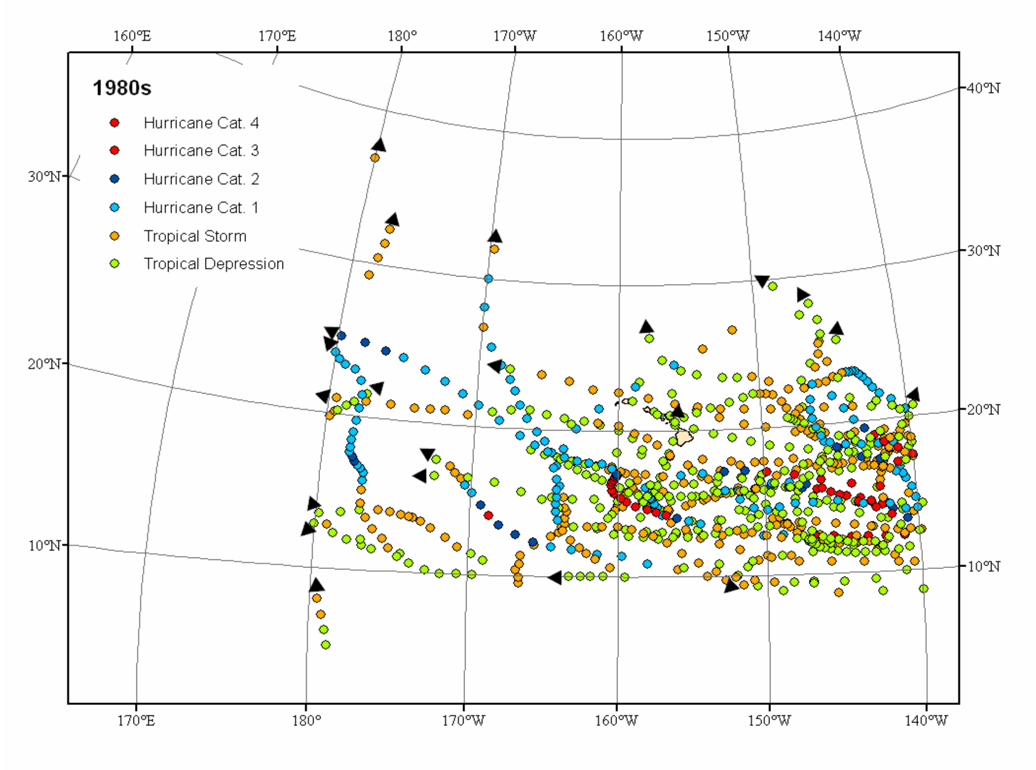

Figure 4.40. TC Tracks for the 1980s.

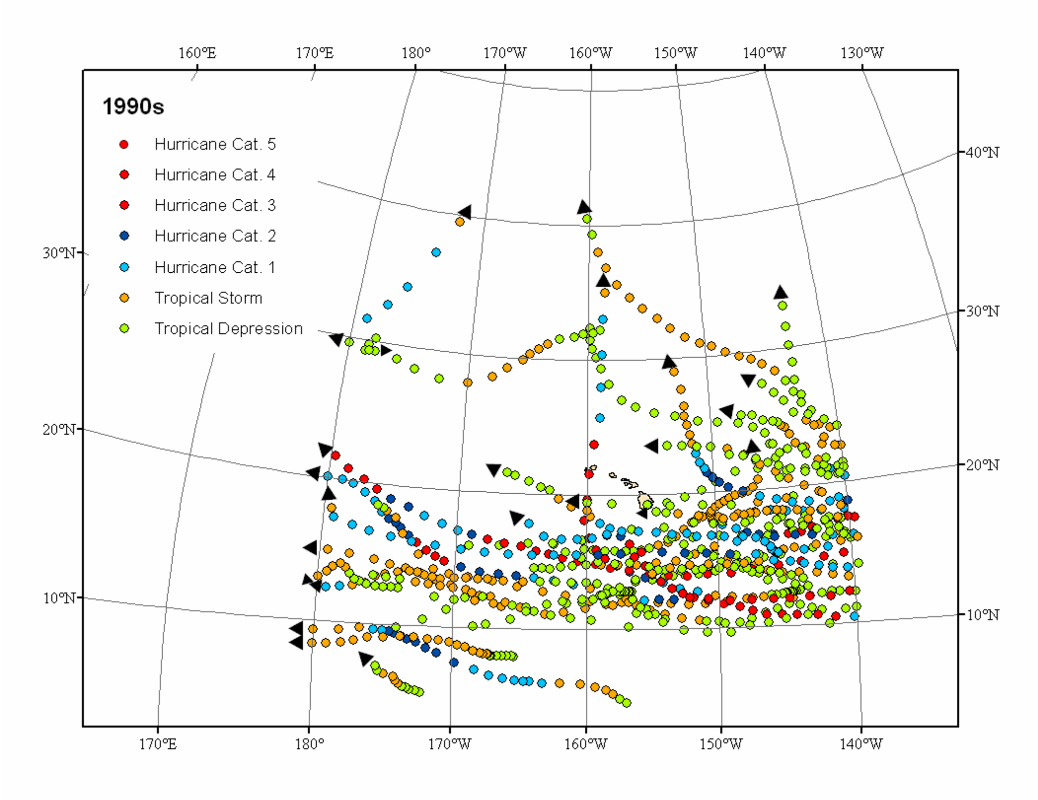

Figure 4.41. TC Tracks for the 1990s.

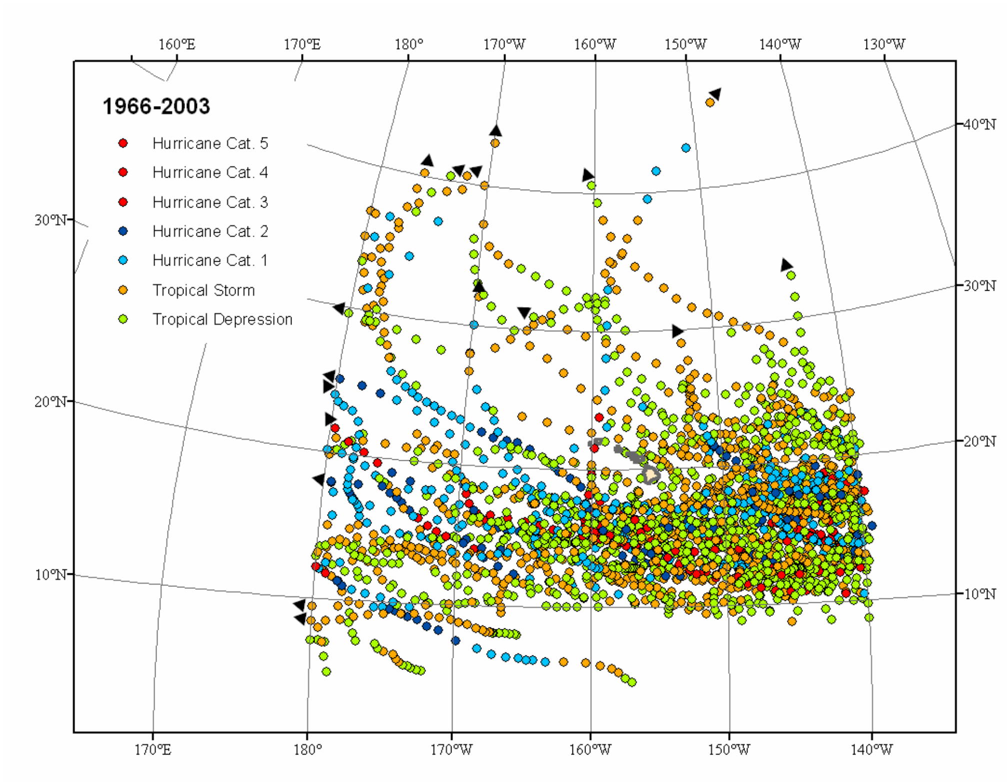

Figure 4.42. TC Tracks for the 38 years from 1966 to 2003.

5 . TC Passage Frequency

TC passage frequency is the number of TCs passing through a square area during a certain period of time. Here, we define the square area to be 2.5^o in latitude by 2.5^o in longitude. First we show the TC passage frequency for the entire 38-year period of 1966 to 2003. On this plot, we find TC activity is mainly confined between 10^{o}N to 30^{o}N over the CNP, with the highest TC passage frequency being located to the southeast of the Hawaiian Islands, around 15-17^{o}N and 142.5-145°W (Figure 5.1). The maximum value is as large as 35, which indicates that 35 TCs have passed though the area during the 38 years period. That is, on average, approximately one TC passage per year is expected in this location. The second highest frequency is found to the south of the Big Island at 15^{o}N, where a total of 25 TCs have passed through that area during 1966 to 2003.

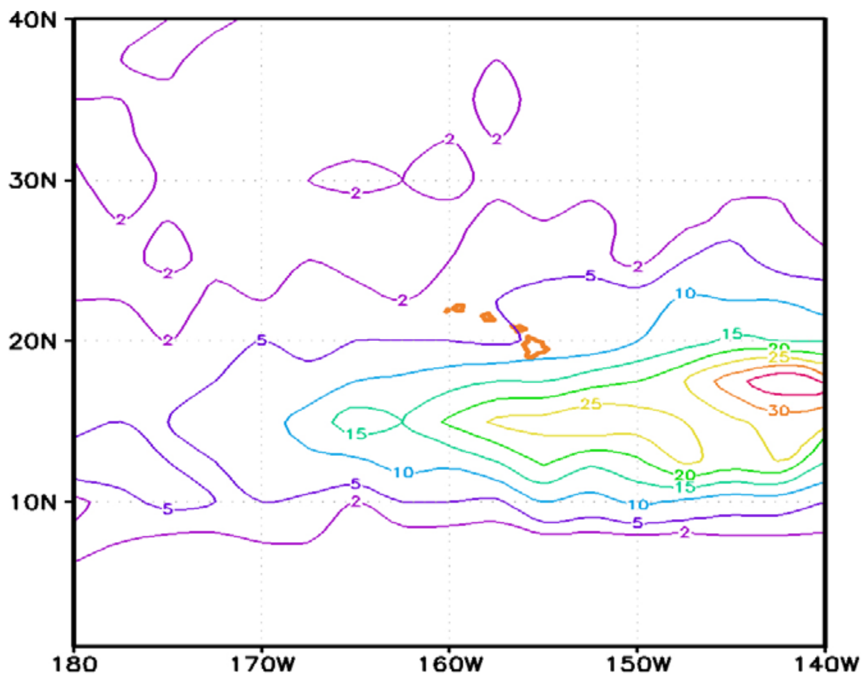

Figure 5.1. TC Passage Frequency. **TC (hurricane, tropical storm and tropical depression) passage frequency during the 38 years from 1966 to 2003.**

The passage frequency for Hurricanes during the 38-year period is shown next (Figure 5.2). Compared with TC passage frequency on the previous plot, Hurricane passage frequency has a smaller meridional extension, which only extends to 25°N. The first and second largest values are found within the same areas as the previous plot, with the magnitudes being reduced by about 50%.

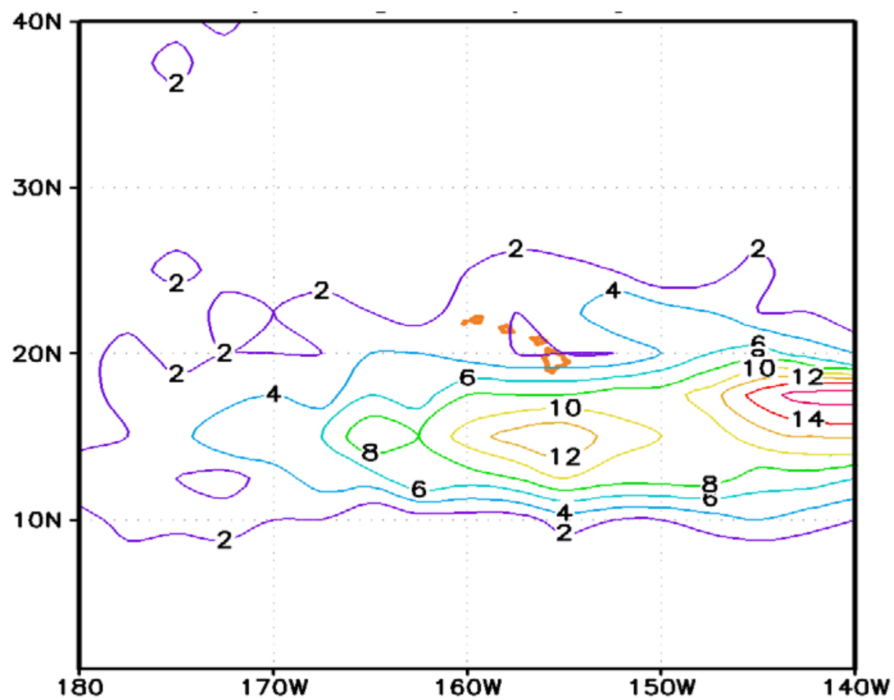

Figure 5.2. Hurricane Passage Frequency during the 38 years from 1966 to 2003.

The next plot shows the number of days out of the 38 years when TC activity is observed over each 2.5° square area (Figure 5.3). The area with the most TC days is located to the southeast of Hawaiian Islands, between 10°N to 20°N and 140°W to 150°W. Here TC activity is observed for 17 days during 1996 to 2003. An area with the second largest value is located to the south of Hawaiian Islands, centered by 15°N and 157.5°W, where TC activity is observed for as many as 15 days.

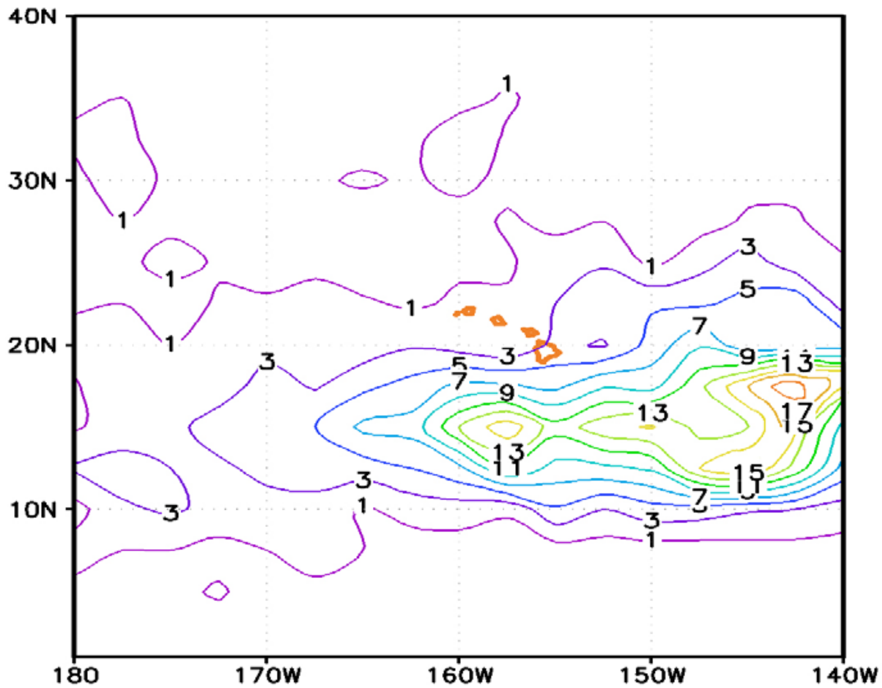

Figure 5.3. TC Passage Days During the 38 years from 1966 to 2003.

Typically, TCs have radial scales of several hundred kilometers, and the region of strong wind and intense precipitation in a TC is about 100 km in radius (Holton 1992). Thus a TC whose center is located within 100 km of each square area might have potential impacts toward areas within the square. Subsequently, we show the TC passage frequency on which TCs passing through the 100 km vicinity of each square area are counted, in addition to TCs passing inside the square (Figure 5.4).

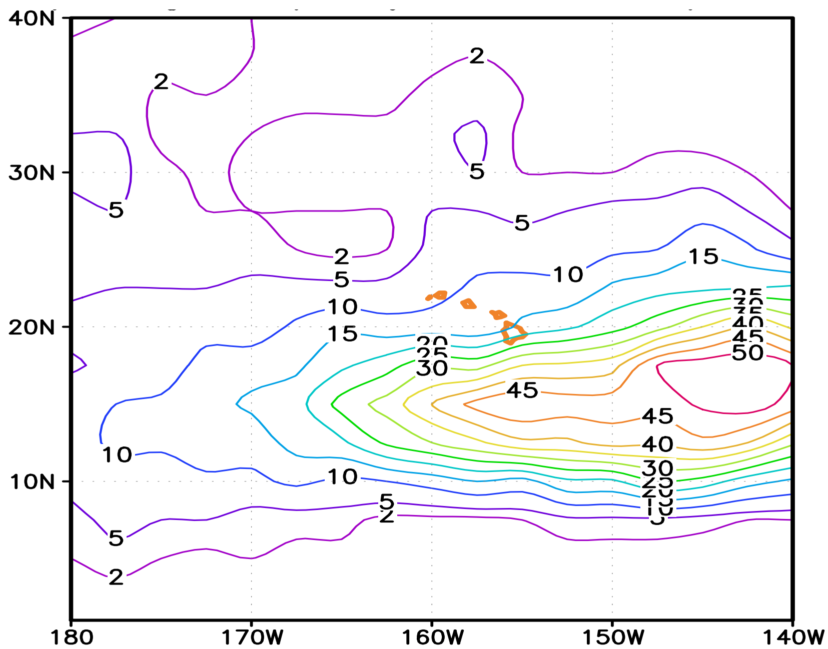

Figure 5.4. Extended TC Passage Frequency during the 38 years from 1966 to 2003.

TC activity varies from month to month during each hurricane season. Thus the climatology of TC passage frequency is also plotted month by month from July to November (Figures 5.5 through Figure 15). Plots are first shown for TC occurrence, followed by plots for Hurricane occurrence. Climatologically, August is the month that experiences the highest activity of both TCs and Hurricanes only, while June experiences the lowest activity of both in the official hurricane season.

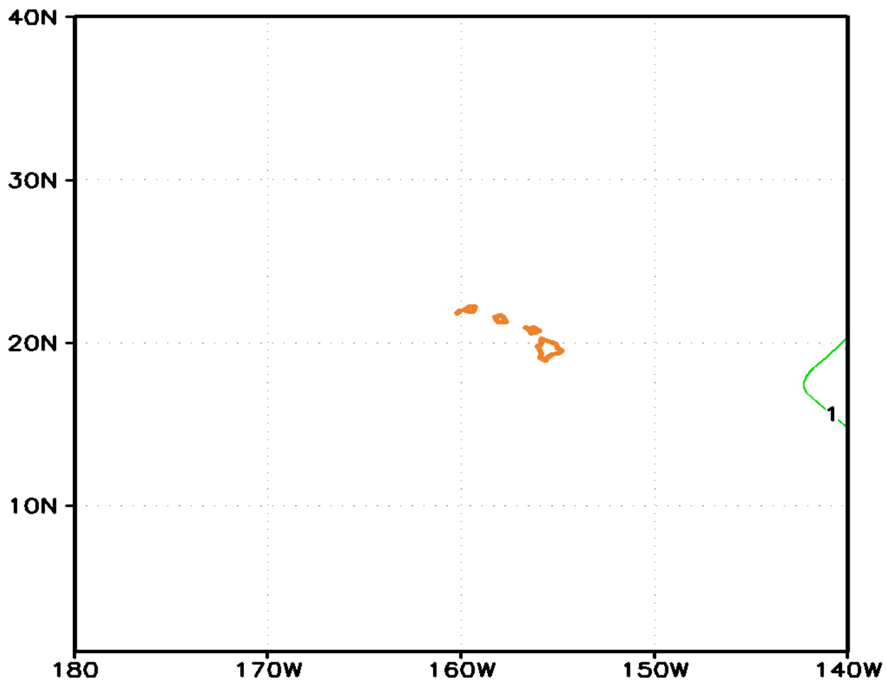

Figure 5.5. TC Passage Frequency in June during the 38 years from 1966 to 2003.

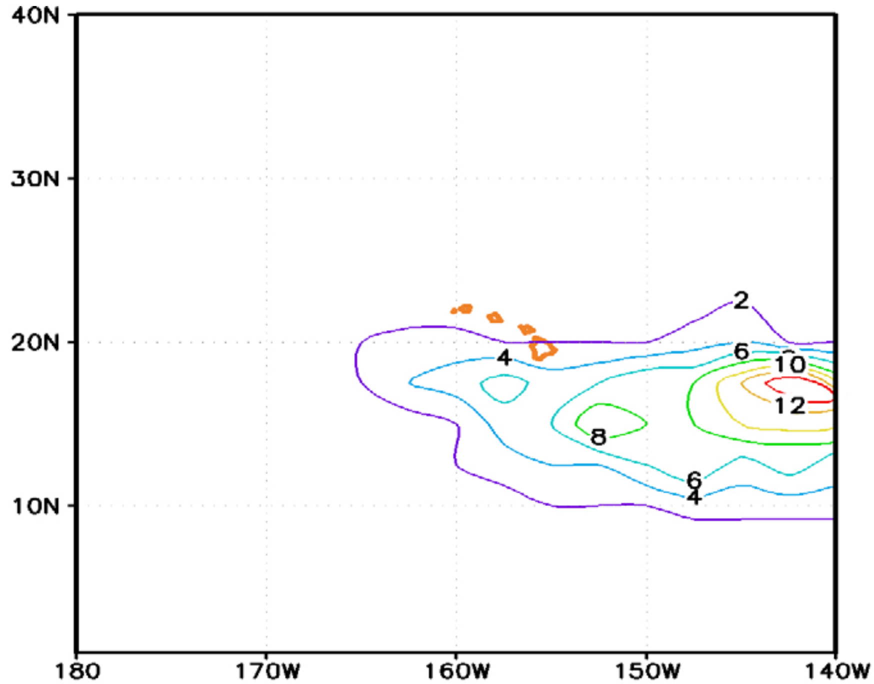

Figure 5.6. Same as Figure 5.5, except for July.

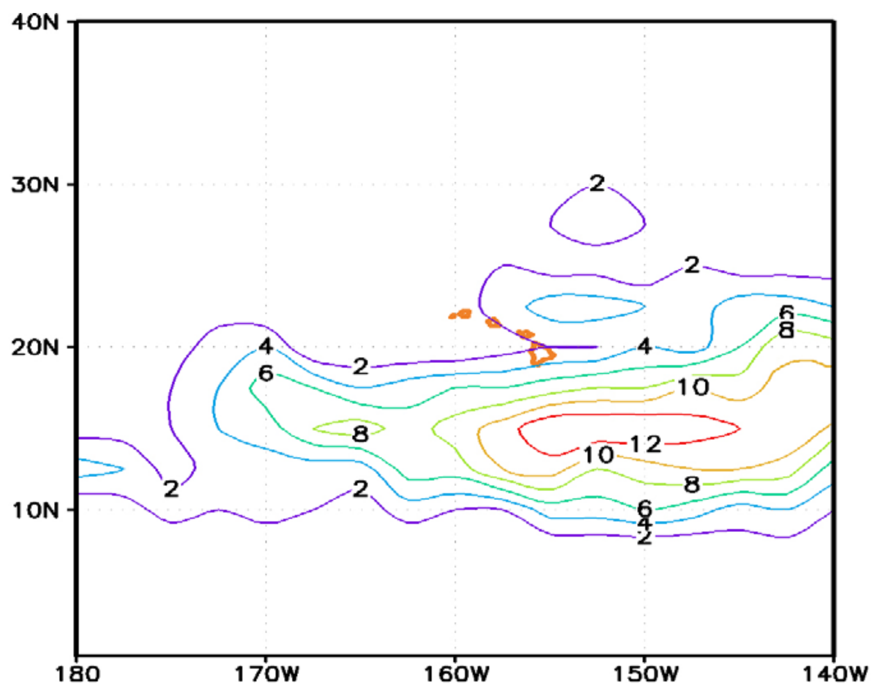

Figure 5.7. Same as Figure 5.5, except for August.

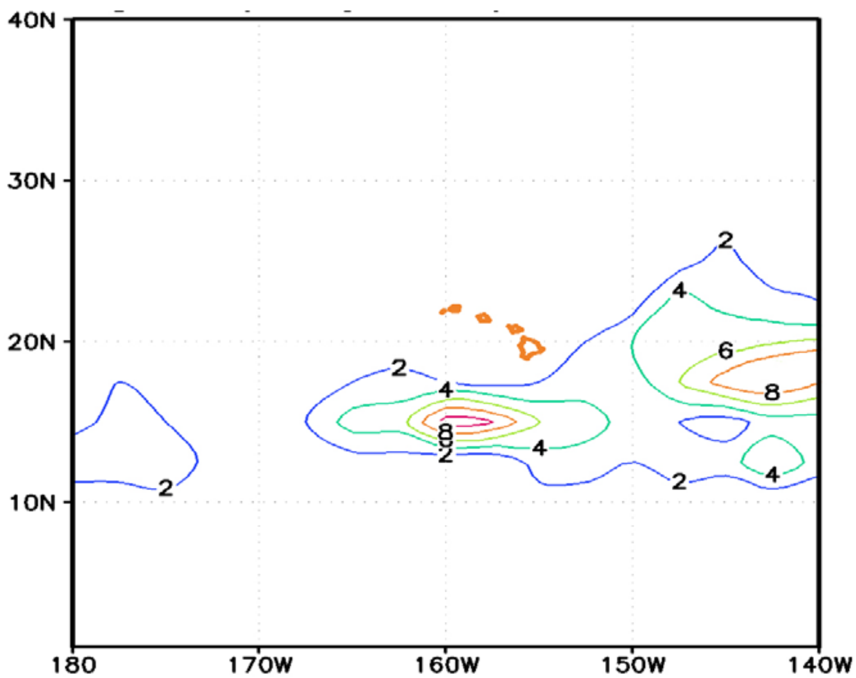

Figure 5.8. Same as Figure 5.5, except for September.

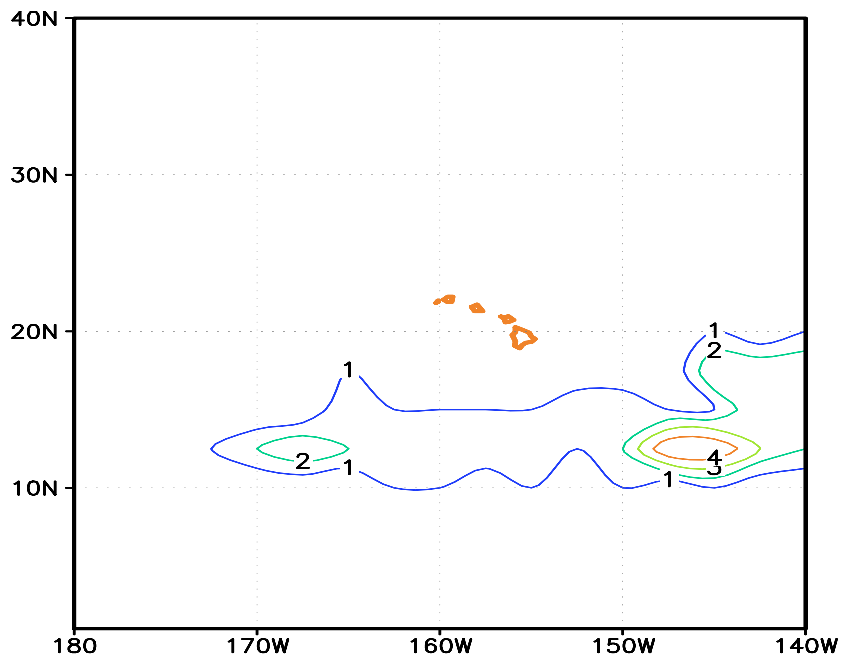

Figure 5.9. Same as Figure 5.5, except for October.

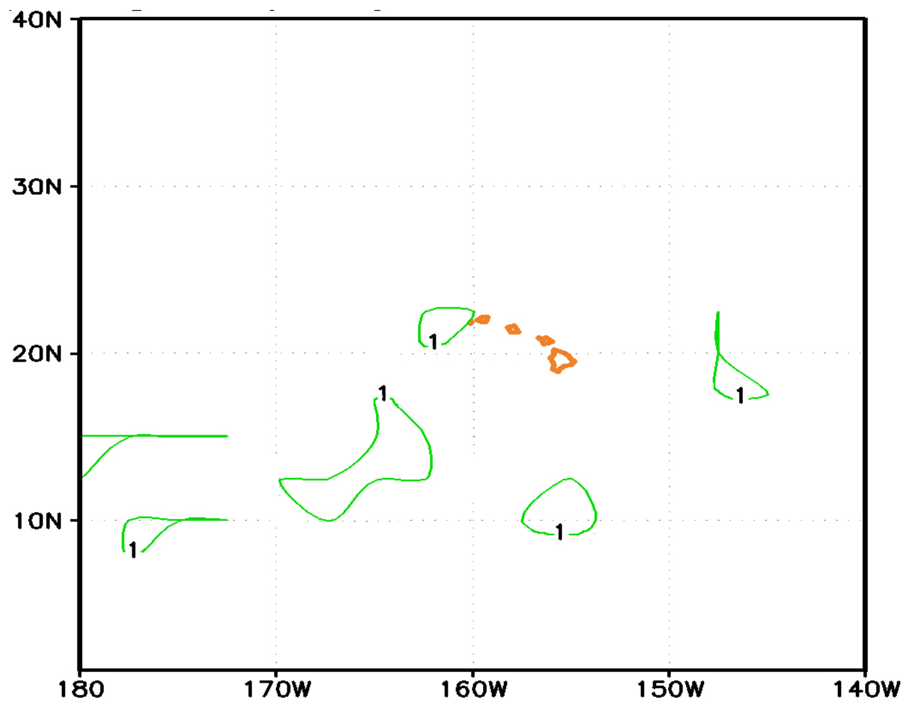

Figure 5.10. Same as Figure 5.5, except for November.

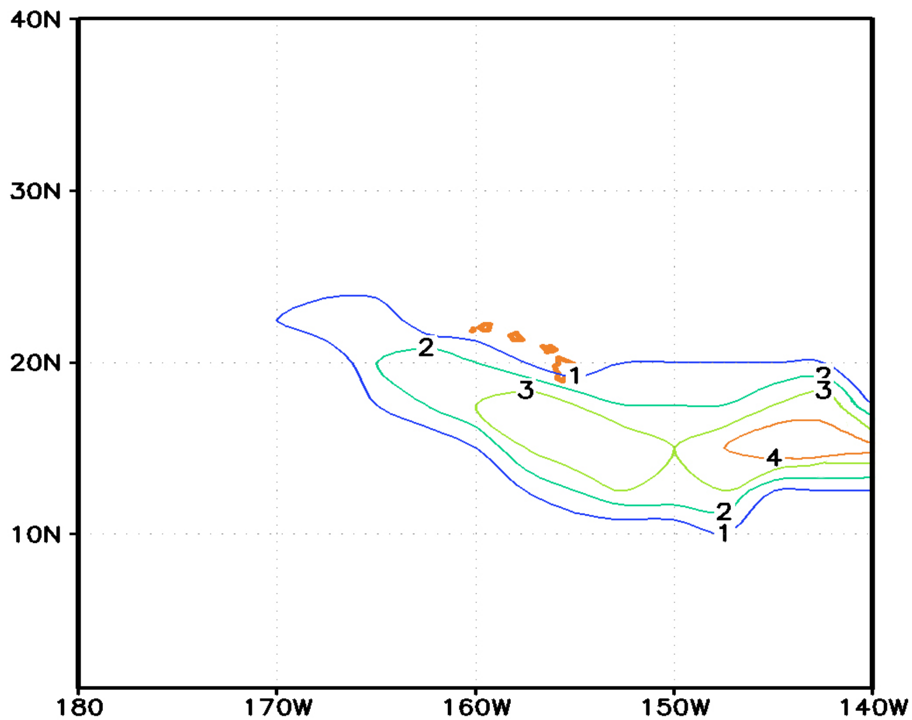

Figure 5.11. Hurricane passage frequency in July during the 38 years from 1966 to 2003.

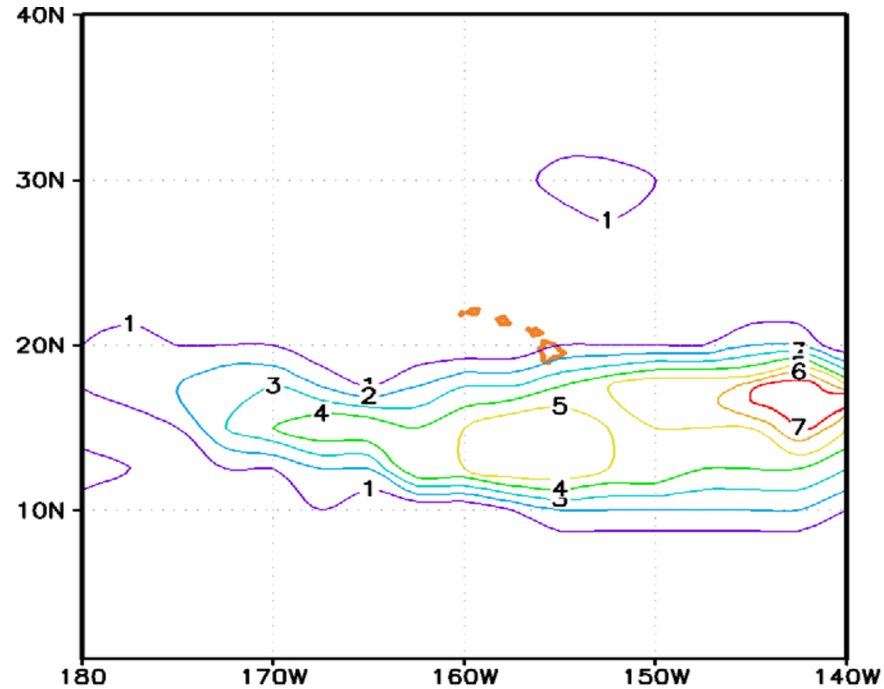

Figure 5.12. Same as Figure 5.11, except for August.

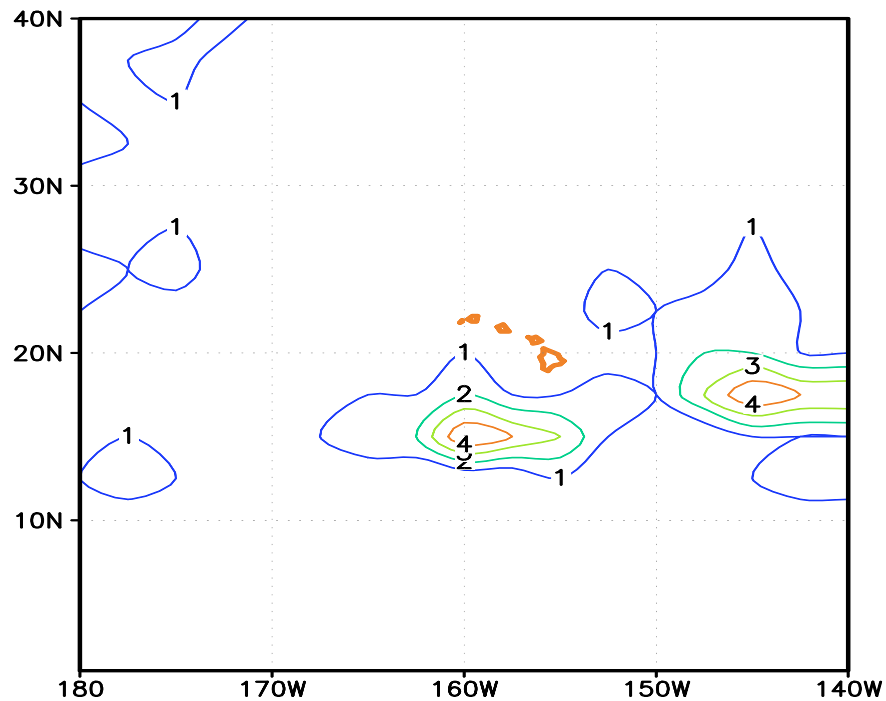

Figure 5.13. Same as Figure 5.11, except for September.

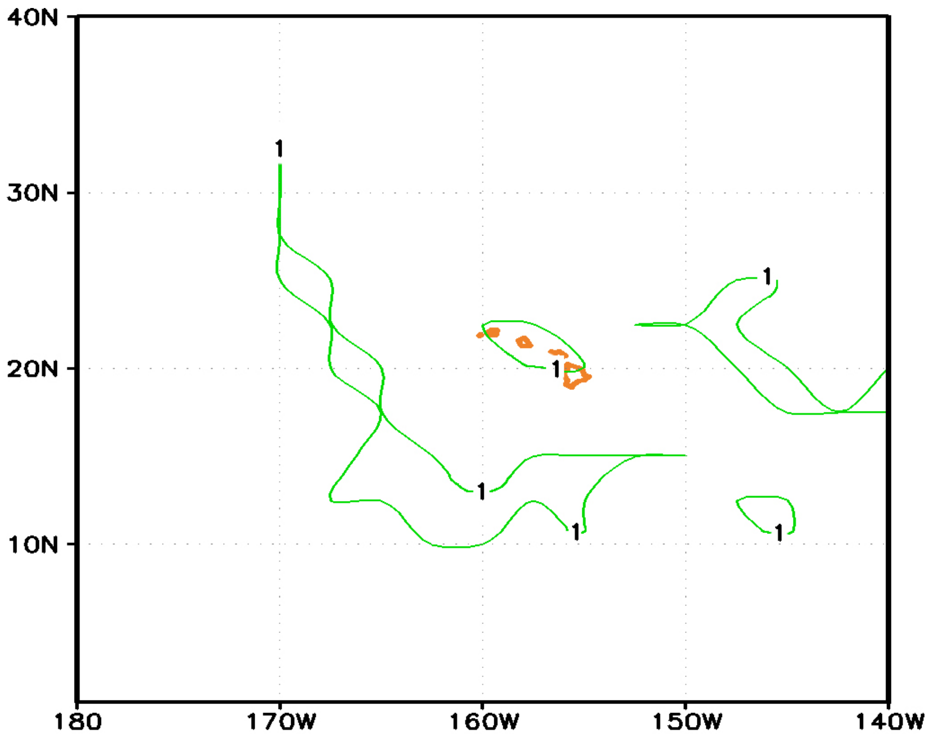

Figure 5.14. Same as Figure 5.11, except for October.

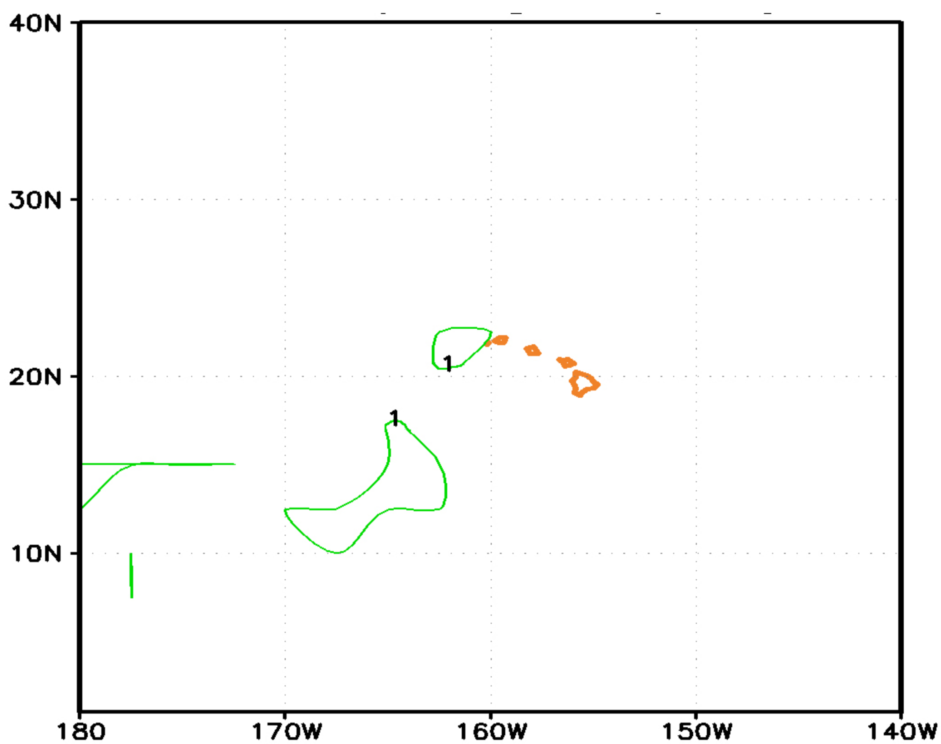

Figure 5.15. Same as Figure 5.11, except for November.

6 . Large-Scale Environmental Conditions

The climatology of five large-scale environmental parameters is plotted month by month from June to November. These parameters include sea surface temperatures in ^{o}C, sea level pressure in hPa, vertical wind shear between 200 hPa and 850 hPa in ms^{-1}, tropospheric layer mean wind between 200 hPa and 850 hPa in m s^{-1}, and precipitable water in kg m^{-2} (mm). The data for large-scale environmental parameters are obtained from the NCEP/NCAR reanalysis dataset, with a horizontal resolution of 2.5^{o} in latitude and longitude. The Grid Analysis and Display System (GrADS) is used to make the plots. The domain was chosen to be from 140^{o}W to the dateline and from the equator to 40^{o}N.

6.1 Sea Surface Temperatures

The climatology of sea surface temperatures (SSTs) is plotted month by month in this section (Figures 6.1-6.6). The general pattern shows that warm SSTs are found over the south and cool SSTs over the north. This pattern is similar to that of precipitable water. Following the annual cycle of TC genesis, warm SSTs gradually shift northward from June to September. SSTs over lower latitudes generally remain unchanged between September and October. Southward retreat is observed from October to November.

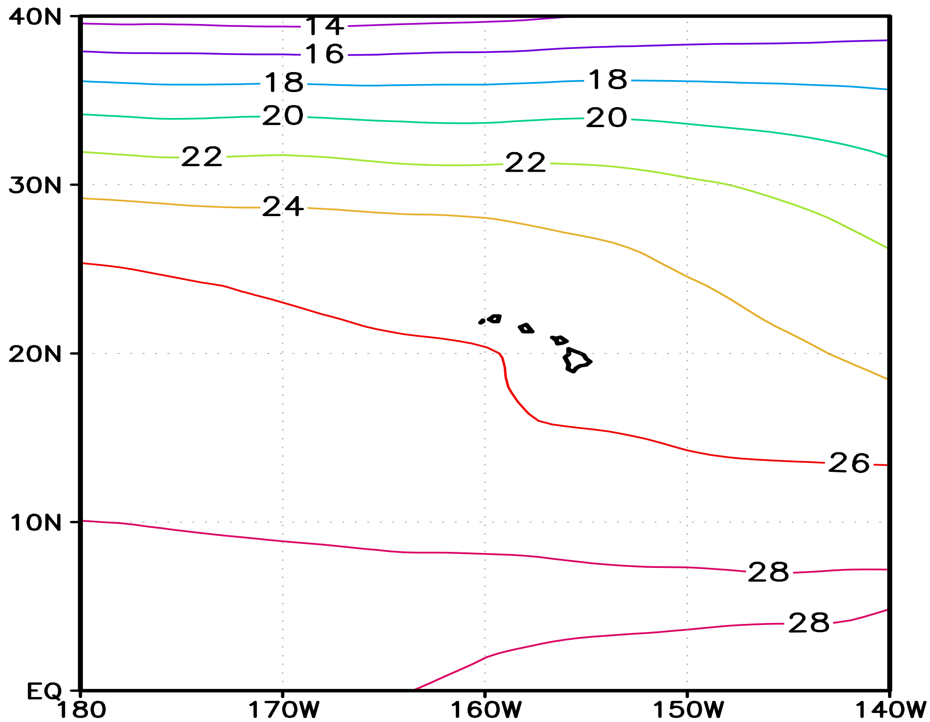

Figure 6.1. Climatological (1966-2003) mean SSTs (^{o}C) in June.

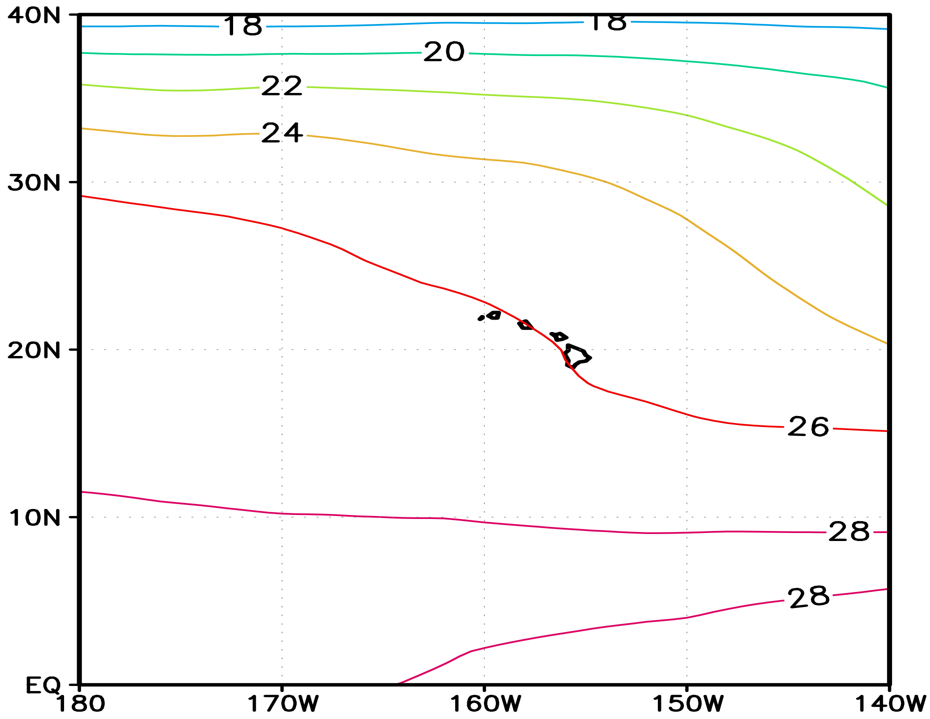

Figure 6.2. Same as Figure 6.1, except for July.

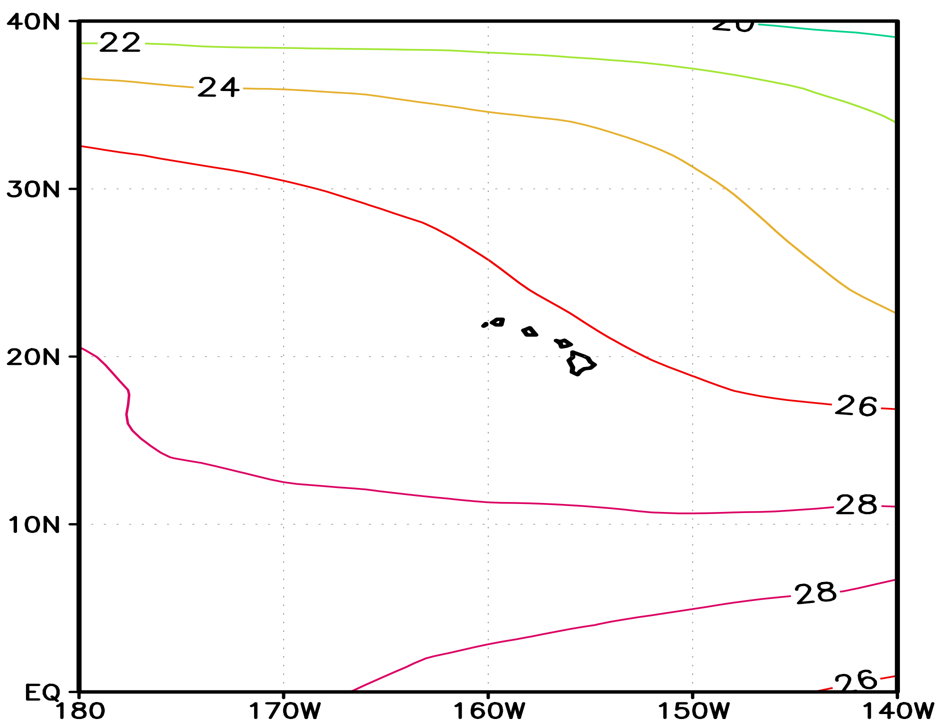

Figure 6.3. Same as Figure 6.1, except for August.

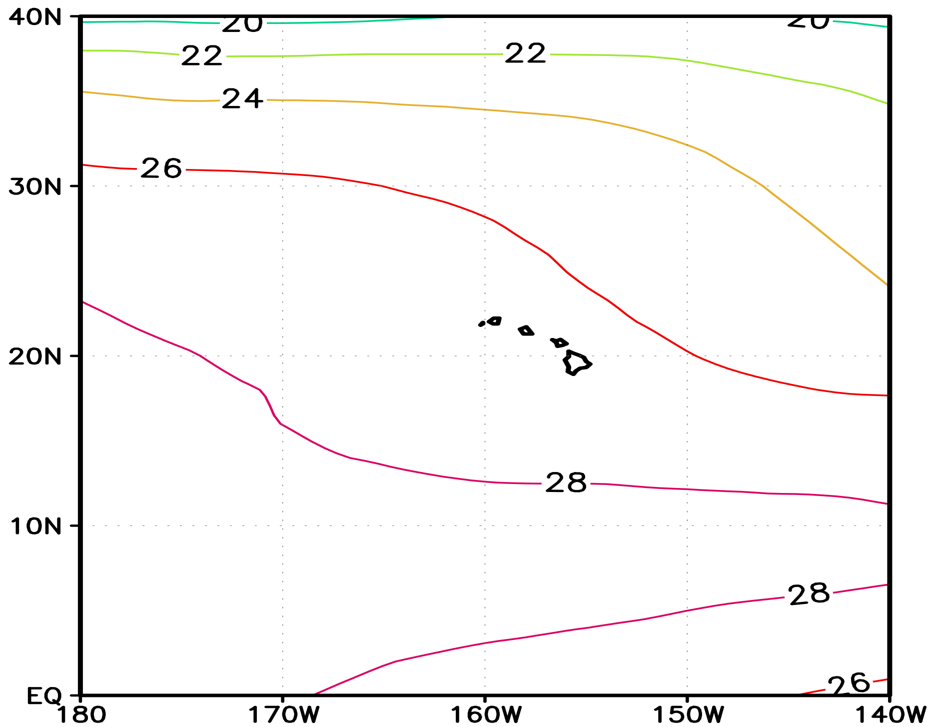

Figure 6.4. Same as Figure 6.1, except for September.

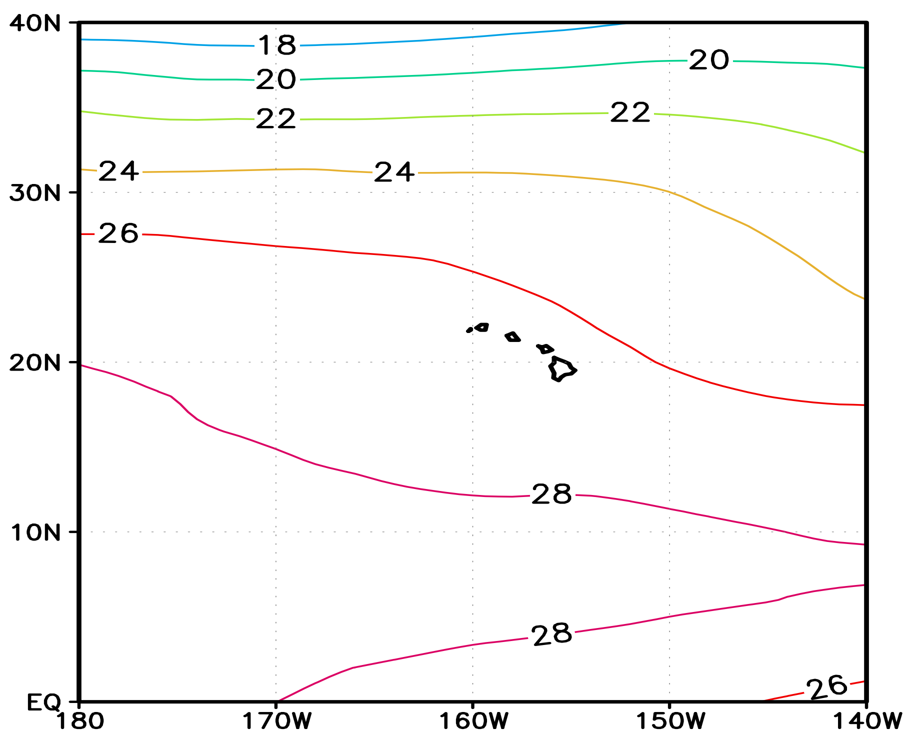

Figure 6.5. Same as Figure 6.1, except for October.

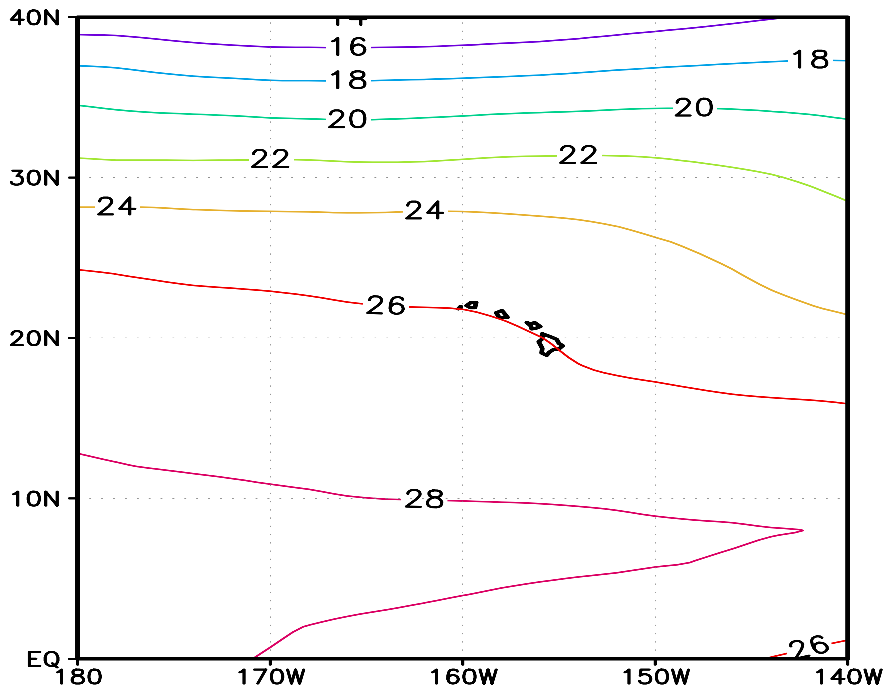

Figure 6.6. Same as Figure 6.1, except for November.

6.2 Sea Level Pressure

Subsequently, climatological plots for sea level pressure (SLP) are shown from June to November (Figures 6.7-6.12). Over the areas of high TC passage frequency, which extends from 140^{o}W to 160^{o}W and 10^{o}N to 20^{o}N, SLP largely remains between 1012 hPa and 1016 hPa, although the 1016 hPa contour is found to the north of 20^{o}N by several degrees during August to November. The major change is related to the strengthening and weakening of the subtropical high to the north of 30^{o}N. During June and July, the subtropical high gradually strengthens in terms of higher pressure and larger area. The weakening of the high system is relatively faster from July to November, especially from August to September when 1024 hPa contour is replaced with 1020 hPa contour.

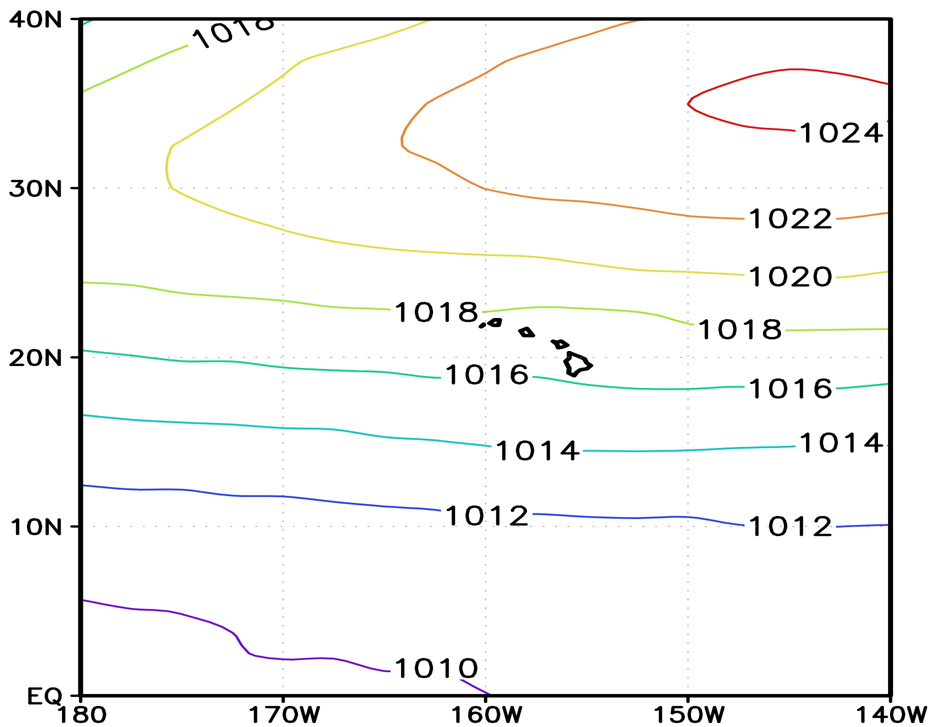

Figure 6.7. Climatological (1966-2003) mean SLP (hPa) in June.

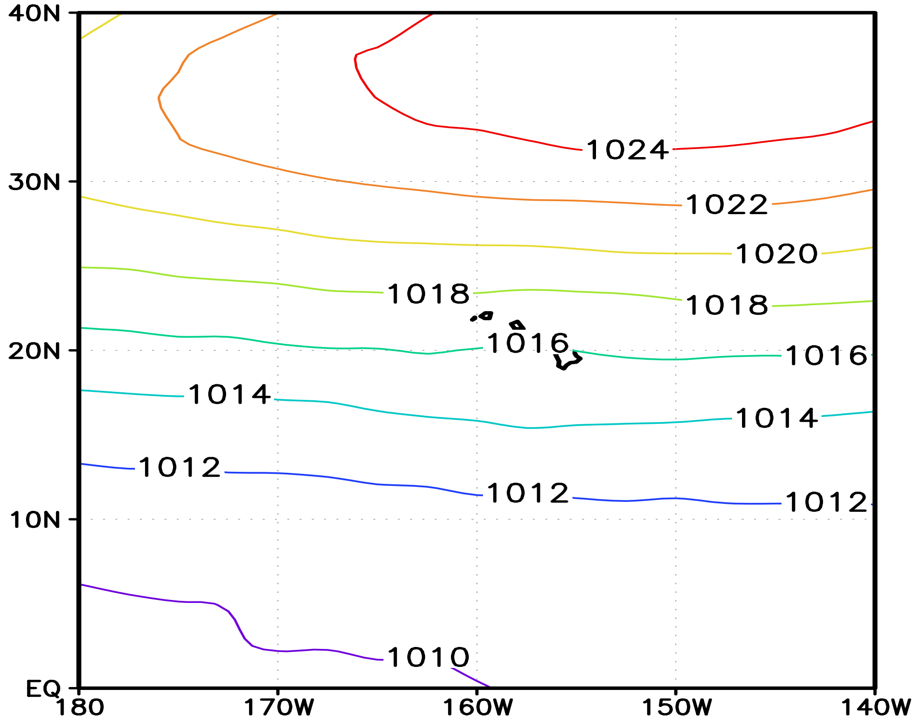

Figure 6.8. Same as Figure 6.7, except for July.

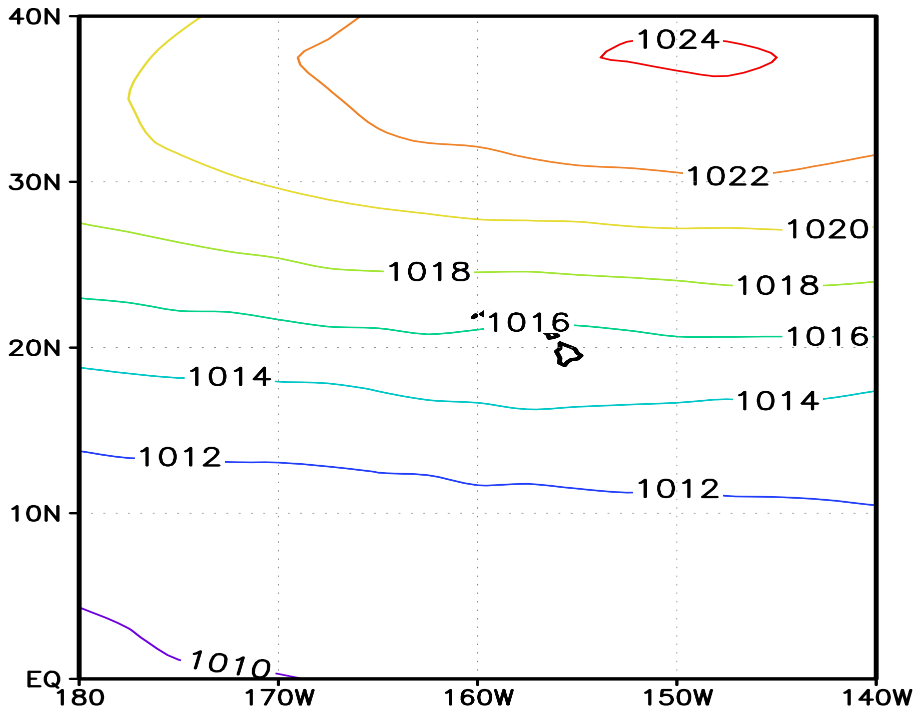

Figure 6.9. Same as Figure 6.7, except for August.

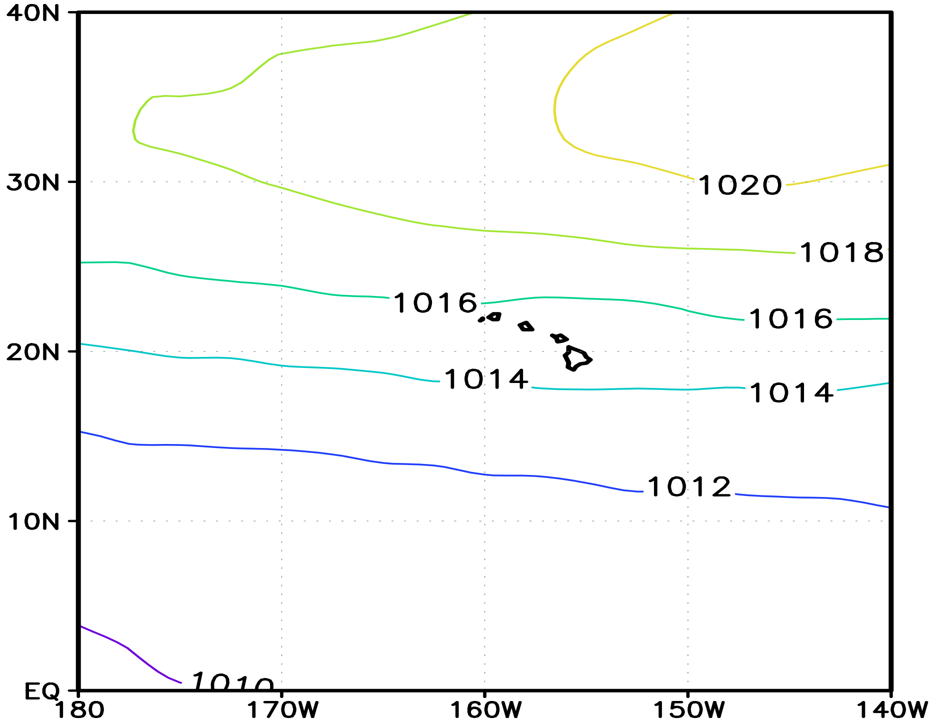

Figure 6.10. Same as Figure 6.7, except for September.

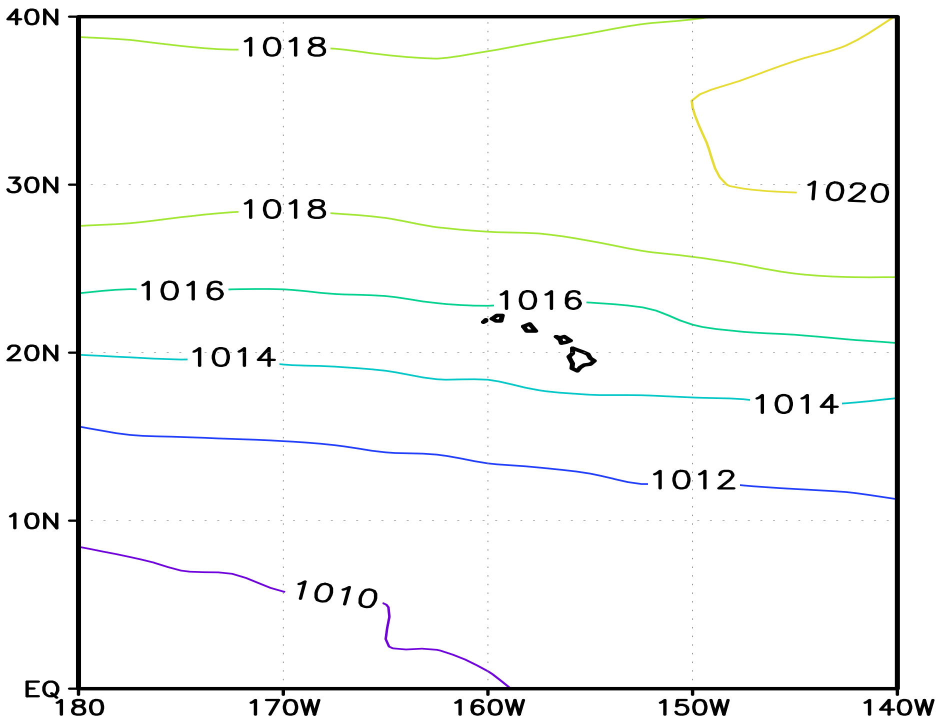

Figure 6.11. Same as Figure 6.7, except for October.

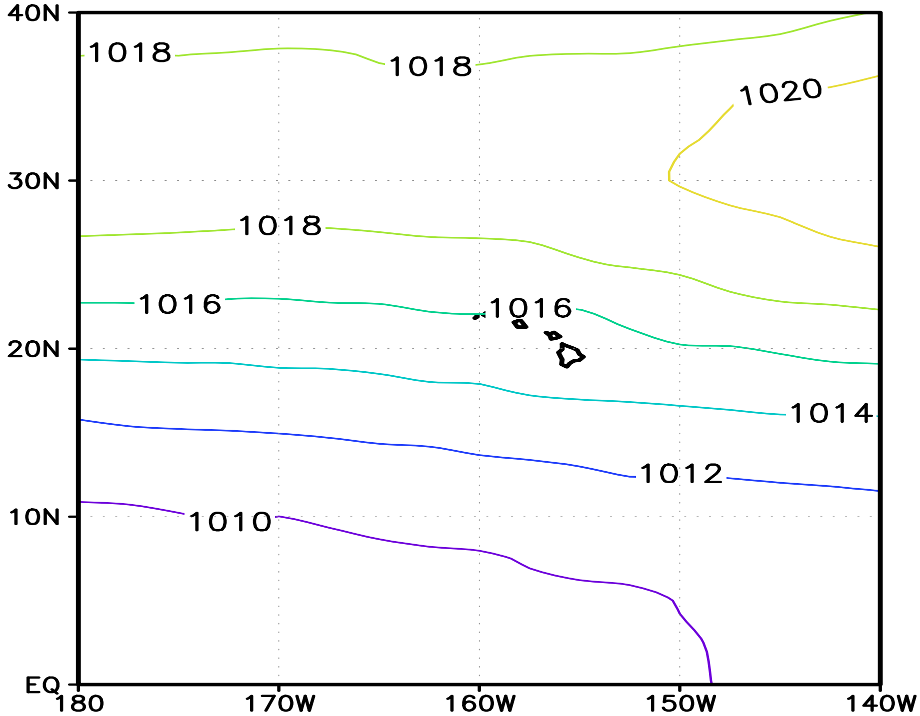

Figure 6.12. Same as Figure 6.7, except for November.

6.3 Vertical Wind Shear

The climatology of vertical wind shear (VWS) between 200 hPa and 850 hPa is shown month by month (Figures 6.13-6.18). In June, VWS with values higher than 24 m s^{-1} are observed over areas of high TC passage frequency to the south of the Hawaiian Islands. From June to September, this area of strong VWS shifts toward the northwest. Meanwhile, strongest VWS is gradually reduced to only 20 m s^{-1} in September. To the southeast of the area of strong VWS, weak VWS becomes dominant over the TC activity region. In August, VWS reaches the lowest value of 4 m s^{-1} here. From September to November, the area of strong VWS moves back toward the TC activity region to inhibit TC genesis.

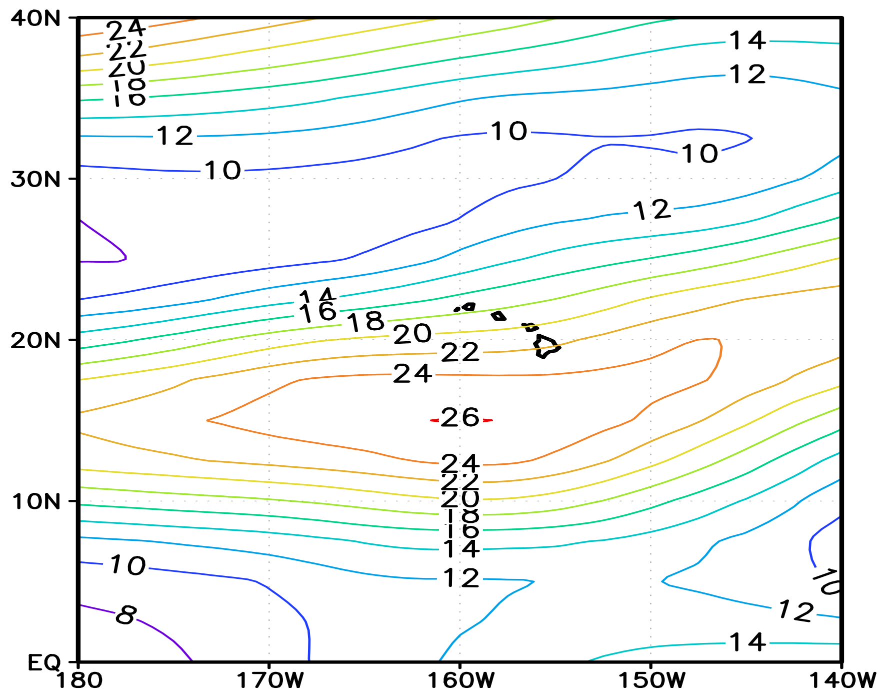

Figure 6.13. Climatological (1966-2003) mean VWS (m s^{-1}) in June.

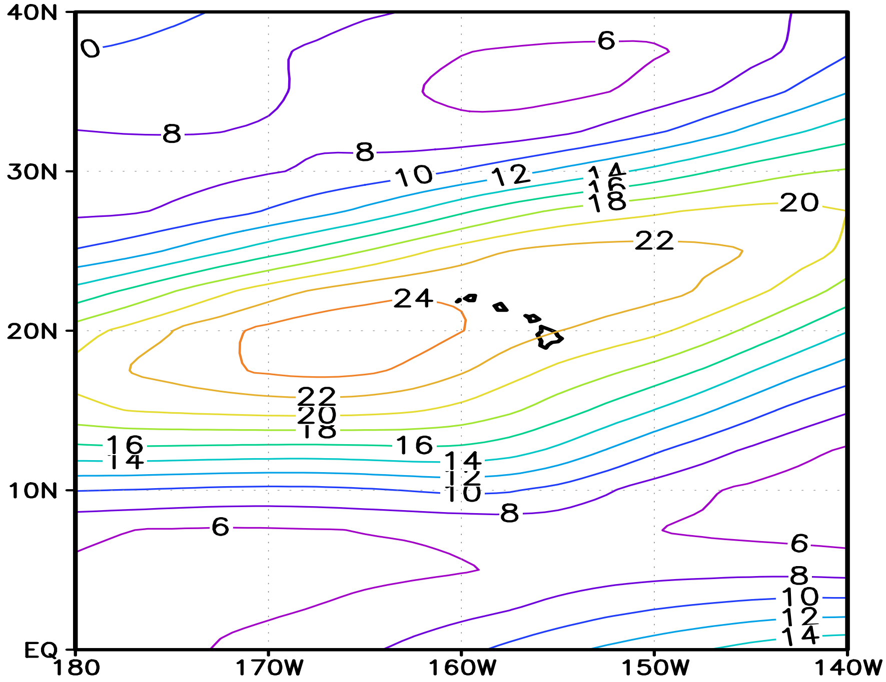

Figure 6.14. Same as Figure 6.13, except for July.

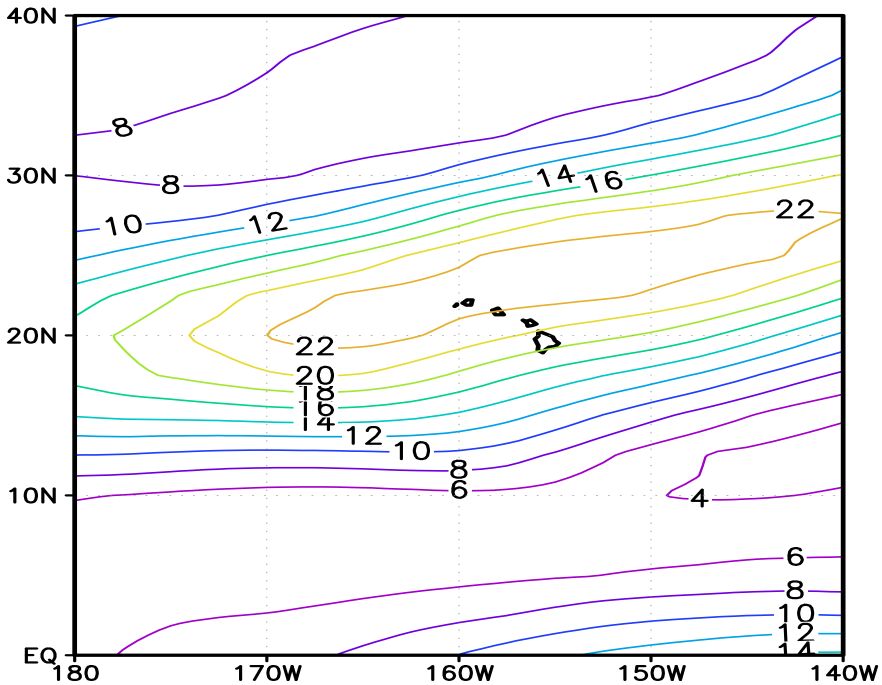

Figure 6.15. Same as Figure 6.13, except for August.

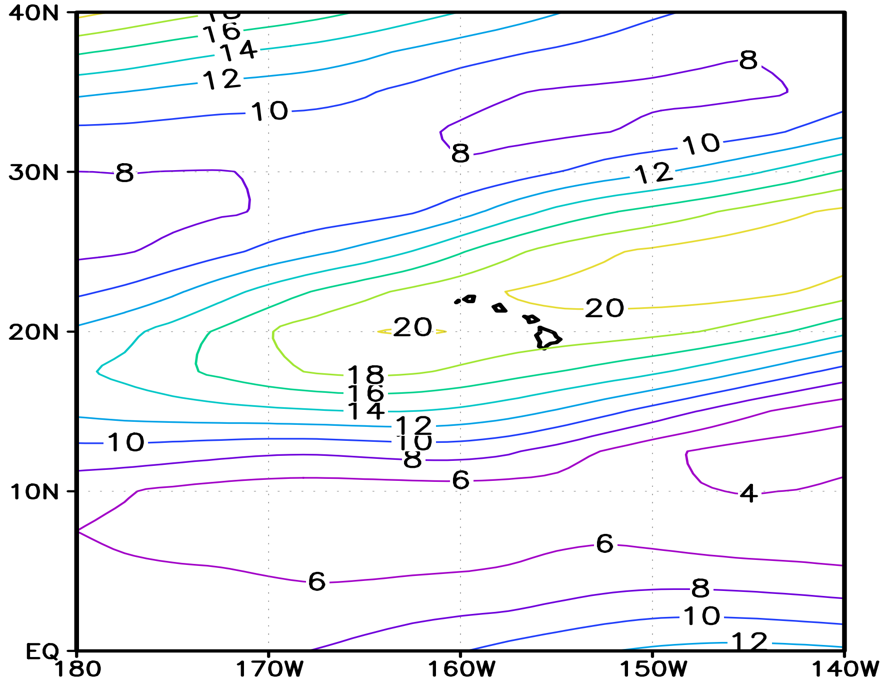

Figure 6.16. Same as Figure 6.13, except for September.

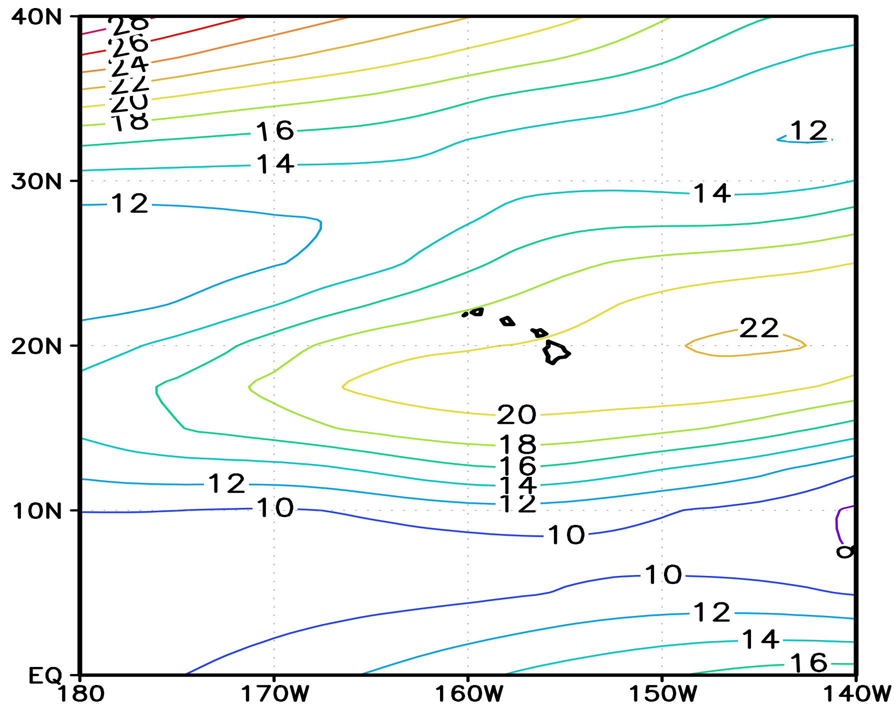

Figure 6.17. Same as Figure 6.13, except for October.

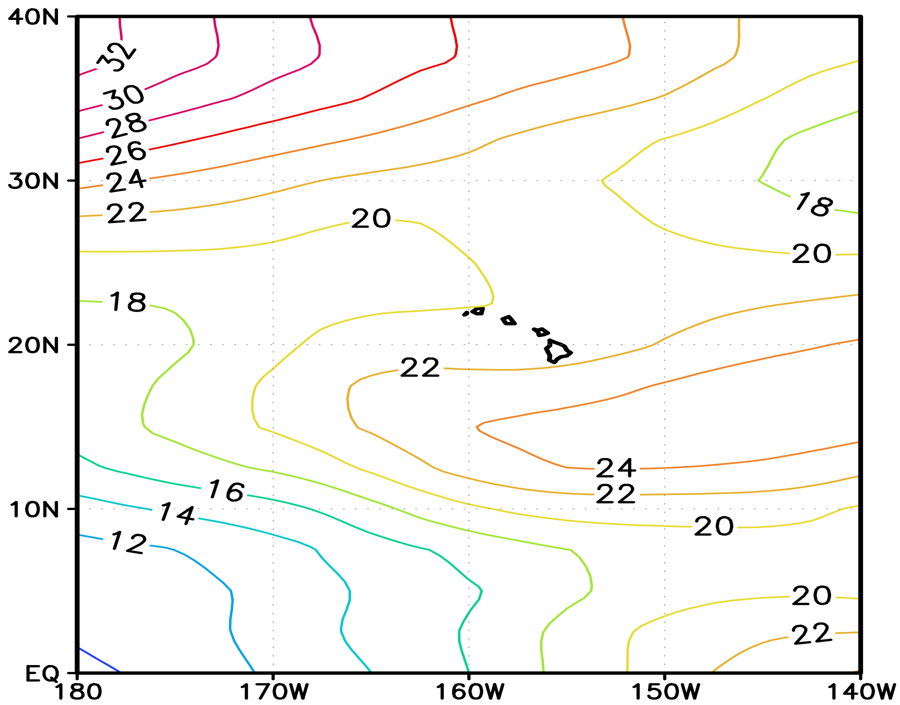

Figure 6.18. Same as Figure 6.13, except for November.

6.4 Tropospheric Layer Mean Wind

The tropospheric layer mean wind (TLMW) is regarded as the steering currents that explain the majority of TC movements (Chan and Gray 1982). The TLMW is defined as

$$TLMW = \frac{1}{p_b - p_t} \int_{p_t}^{p_b} V dp \quad ,$$

where p_b is taken as 850 hPa and p_t as 200 hPa. The TLMW is numerically integrated employing wind data at 8 levels from 850 hPa through 200 hPa. The climatology of TLMW is shown for each month from June through November (Figures 6.19-6.24). These figures provide a synopsis of the average steering flow. A clockwise circulation between 15°N-25°N over the eastern half of the CNP is evident. This circulation extends further westward from June to August, and then weakens in the following months. Locally, strongest easterly steering flow is present between the equator and 10°N, an area to the south of the main TC activities. From June to August, easterly currents gradually strengthen and occupy the major TC activity region between 10°N to 20°N. The increased easterly steering flow could bring more TCs formed over the eastern North Pacific to move into the CNP. Meanwhile, easterly flow could maintain TCs over the warm waters at the lower latitudes to keep their intensity. Starting from August till the end of the hurricane season, easterly flow over this region gradually weakens, and westerly flow gradually penetrates into the CNP from the higher latitudes.

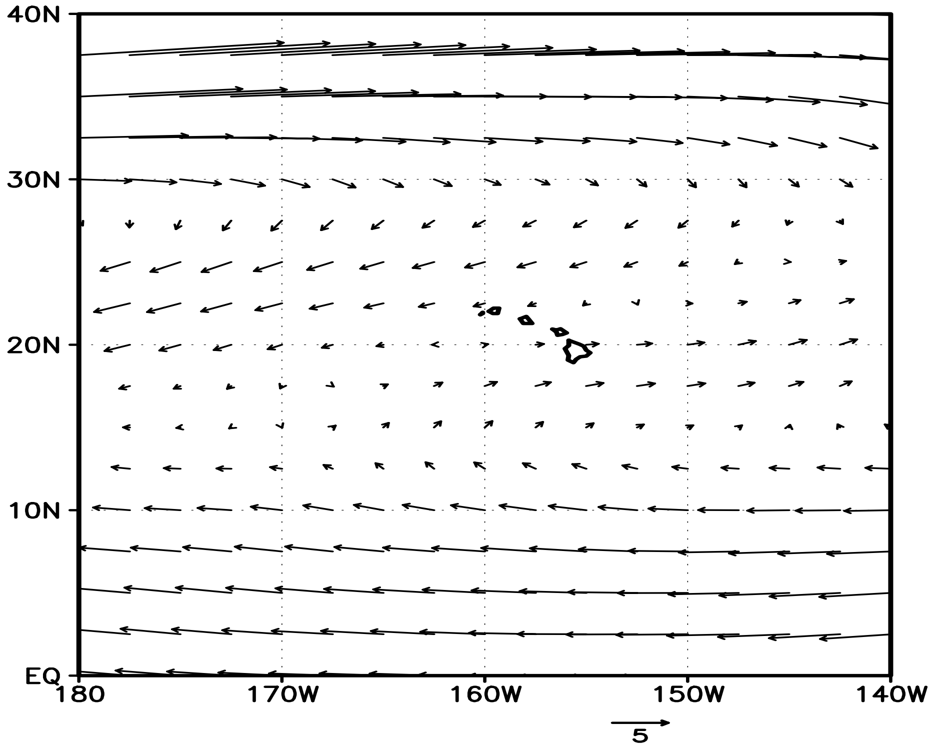

Figure 6.19. Climatological (1966-2003) mean TLMW (m s^{-1}) in June.

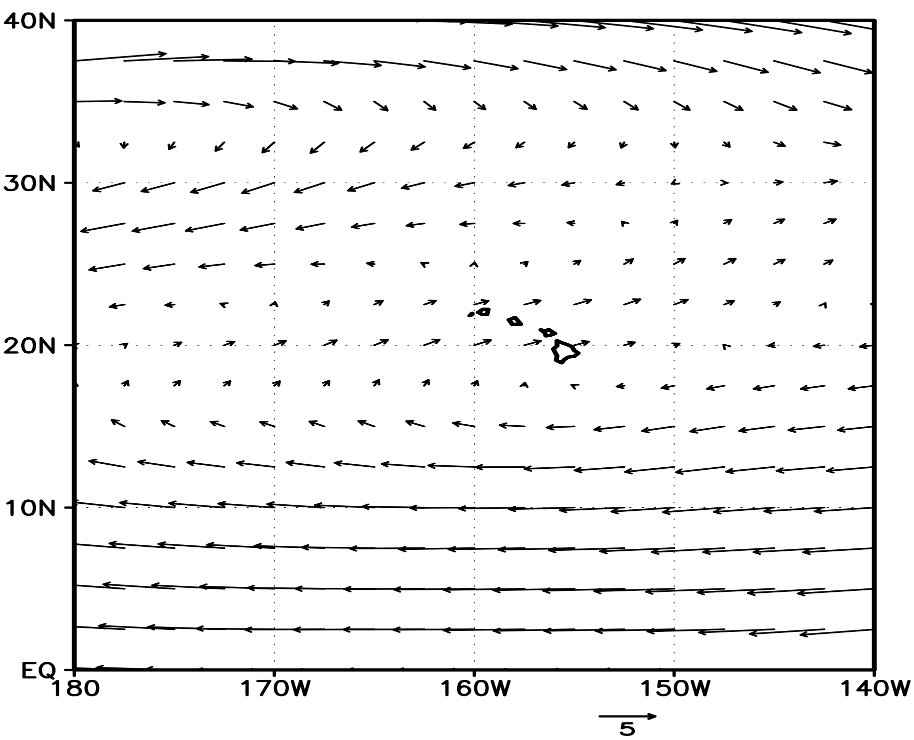

Figure 6.20. Same as Figure 6.19, except for July.

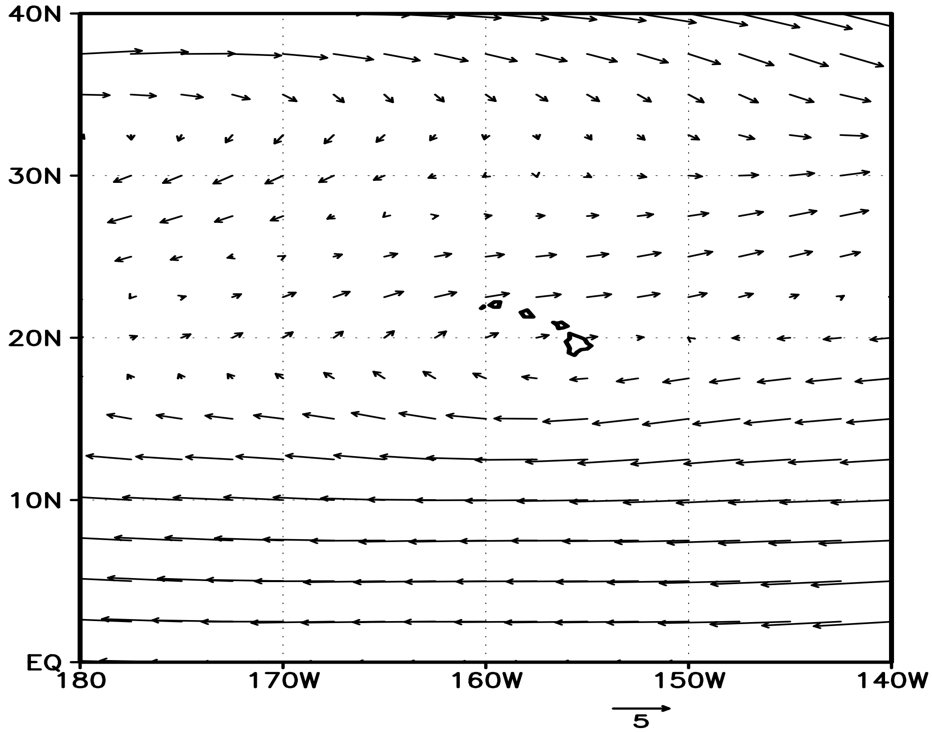

Figure 6.21. Same as Figure 6.19, except for August.

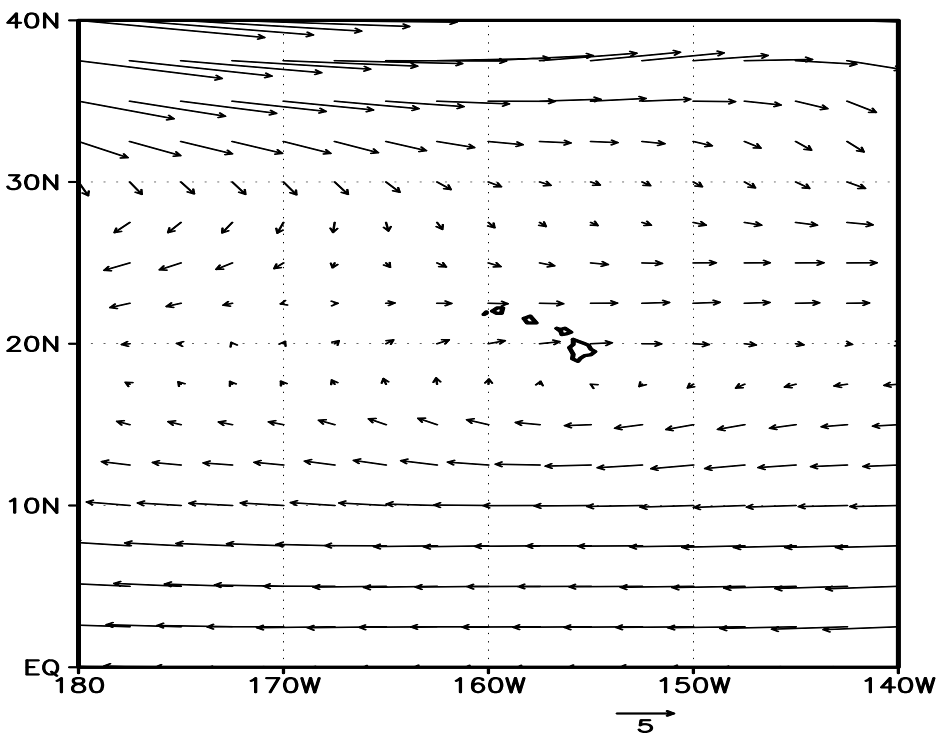

Figure 6.22. Same as Figure 6.19, except for September.

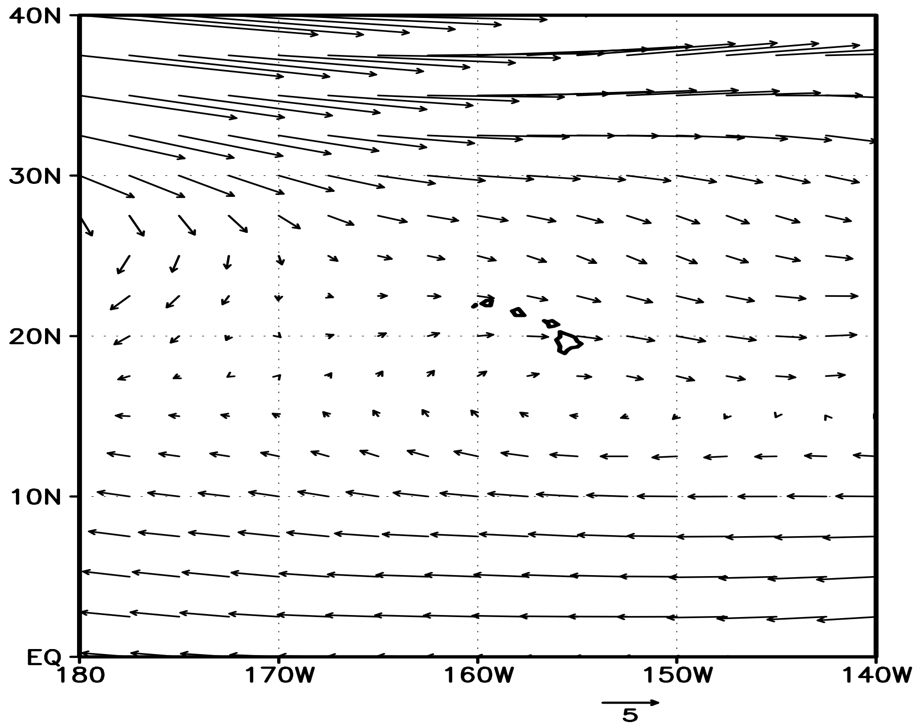

Figure 6.23. Same as Figure 6.19, except for October.

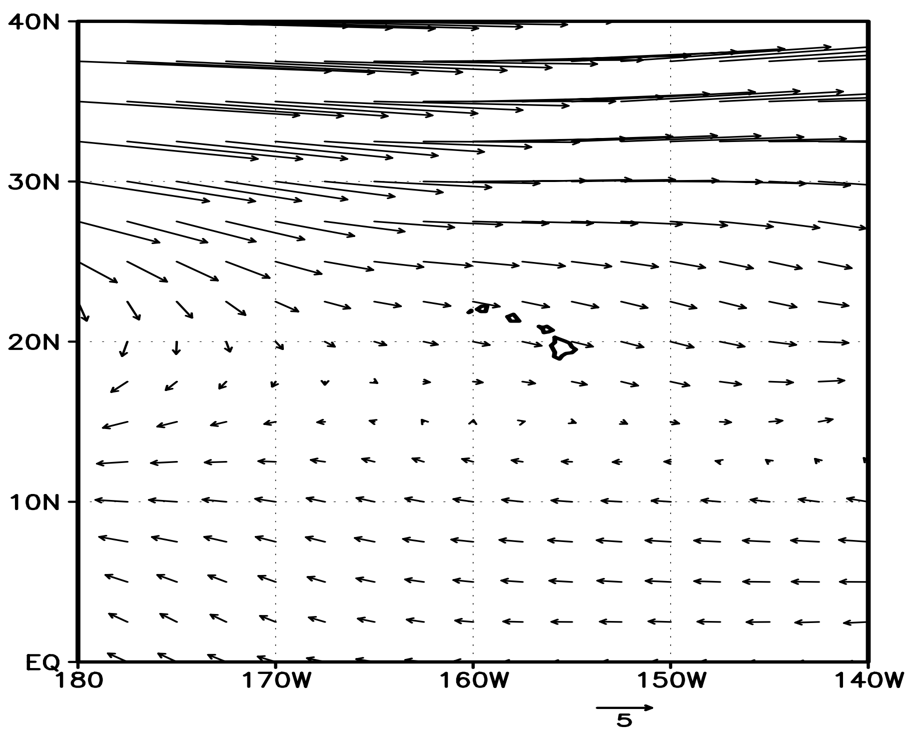

Figure 6.24. Same as Figure 6.19, except for November.

6.5 Precipitable Water

The plots for precipitable water are shown in Figures 6.25-6.30. Generally speaking, the amount of precipitable water is higher in the deep tropics and decreases with increasing latitudes. Consistent with the annual cycle of TC genesis, large amount of precipitable water gradually shifts northward from June to August. The southward retreat of large precipitable water content from August to November is much slower and erratic.

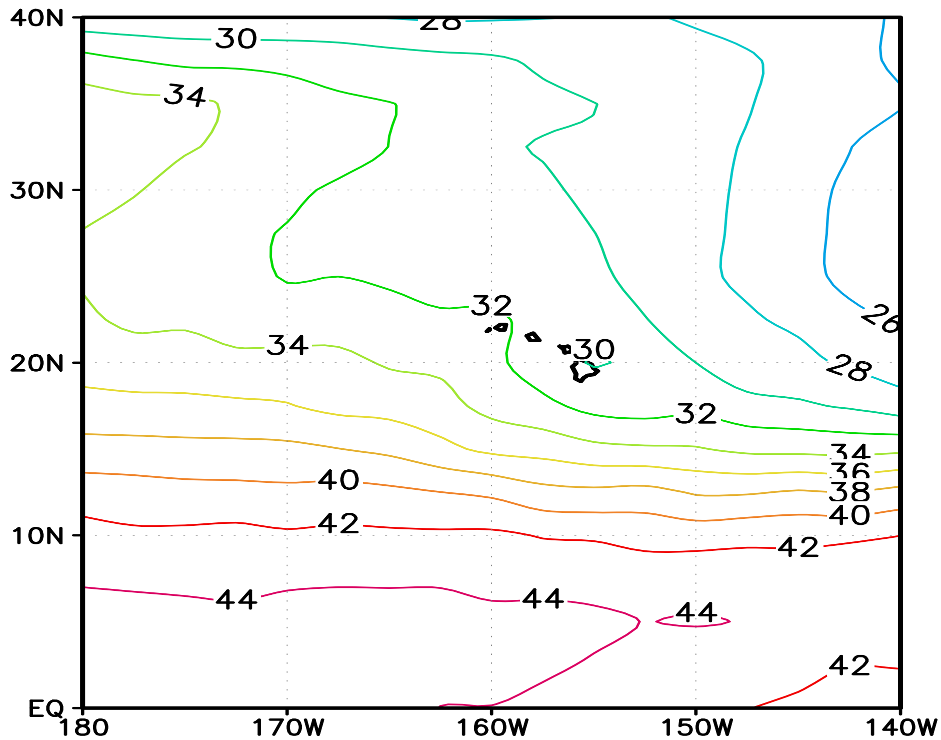

Figure 6.25. Climatological (1966-2003) mean precipitable water (mm) in June.

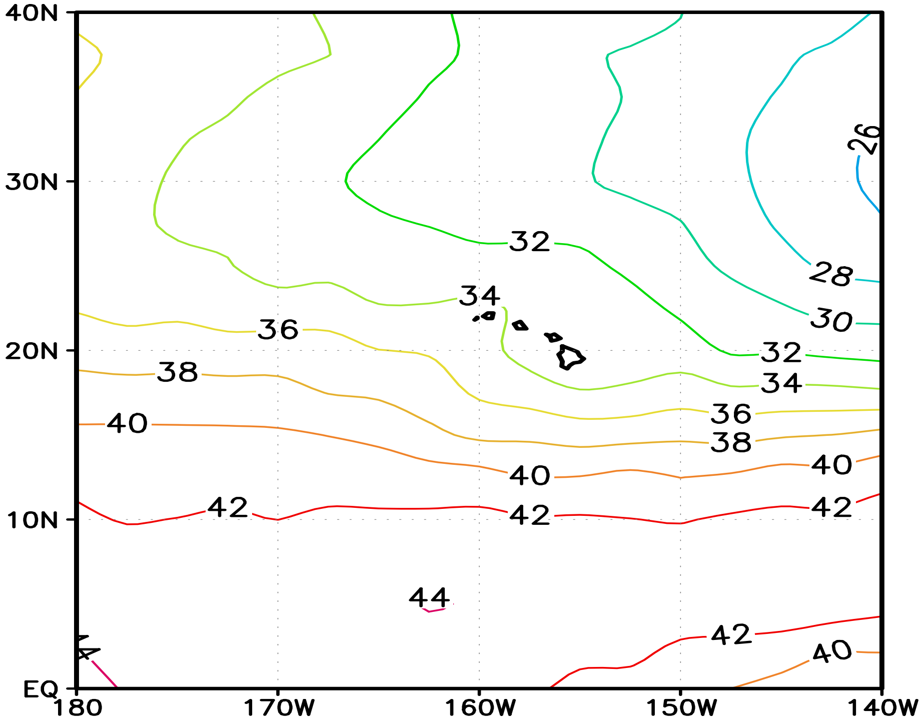

Figure 6.26. Same as Figure 6.25, except for July.

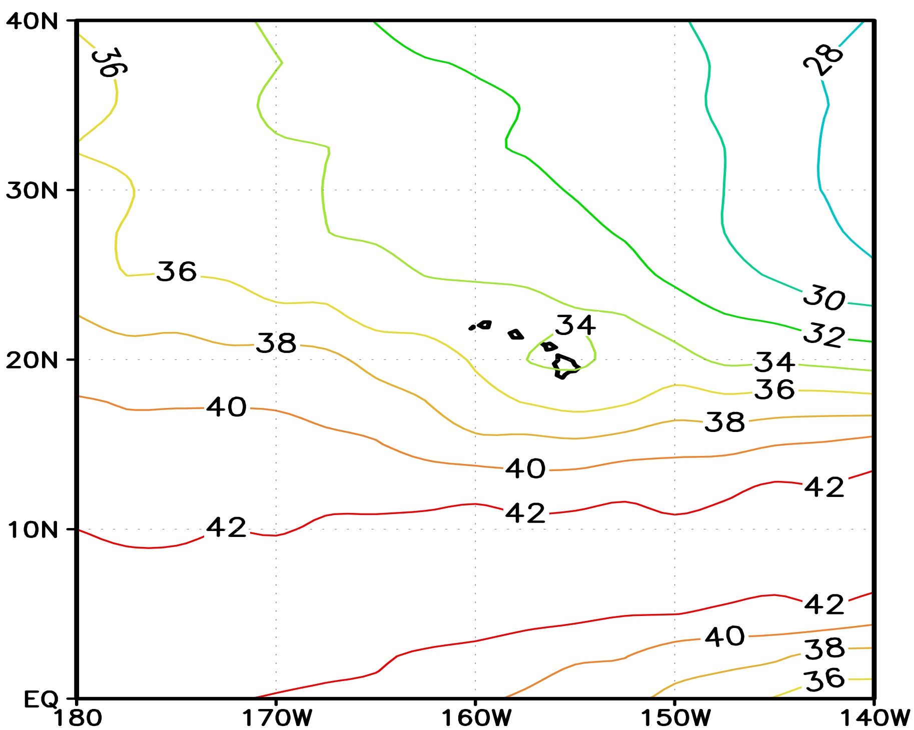

Figure 6.27. Same as Figure 6.25, except for August.

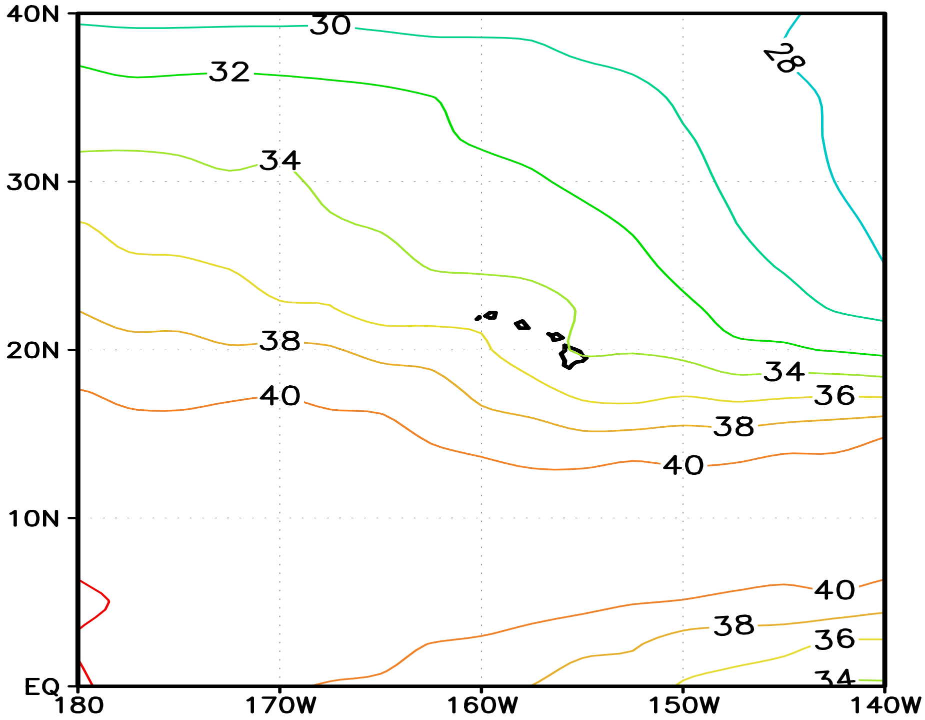

Figure 6.28. Same as Figure 6.25, except for September.

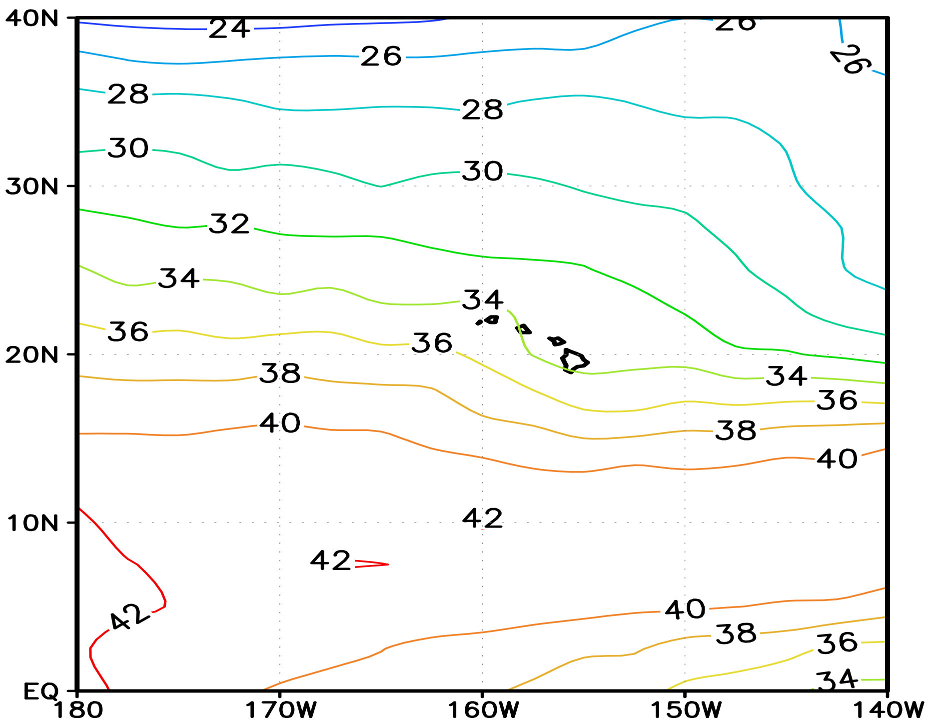

Figure 6.29. Same as Figure 6.25, except for October.

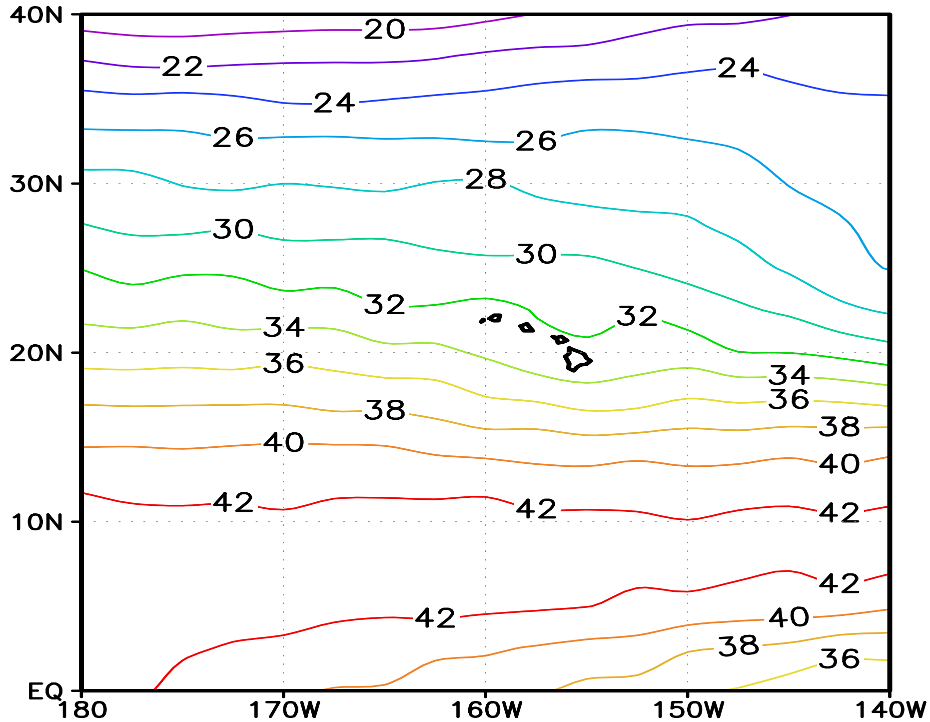

Figure 6.30. Same as Figure 6.25, except for November.

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8. Glossary

Tropical depression: A low pressure system with cyclonic (counterclockwise) circulation and sustained maximum wind speed 38 miles per hour or less.

Tropical storm: A distinct low pressure system with cyclonic circulation and sustained maximum wind speed of 39-73 miles per hour. At this stage, a name is given.

Hurricane: An intense storm of tropical origin with sustained winds exceeding 74 miles per hour.

Saffir-Simpson Hurricane Damage-Potential Scale:

Saffir-Simpson Hurricane Scale	
Hurricane Cat. 5	> 155 mph
Hurricane Cat. 4	131-155 mph
Hurricane Cat. 3	111-130 mph
Hurricane Cat. 2	96-110 mph
Hurricane Cat. 1	74-95 mph

Remnant low: a low pressure system near sea level with weak maximum sustained wind speeds and no deep convection.