551.515.2:551.553.8 (512.317)

ROYAL OBSERVATORY, HONG KONG

Technical Note No. 66

TROPICAL CYCLONES CAUSING PERSISTENT GALES AT THE ROYAL OBSERVATORY 1884-1957 AND AT WAGLAN ISLAND 1953-1980

by

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1. INTRODUCTION

In many of the Royal Observatory's publications such as Meteorological Results Part III, there is a list of tropical cyclones that have given rise to gales, that is, mean hourly wind speeds of 34 knots or more at the Royal Observatory. For the years 1884-1938, this list was prepared using the Observatory's original published wind data with a correction factor of 2.2/3.0. However, Heywood (1939) analysed hourly readings for 1938 and found that the "run" of the cup anemometer should be multiplied by a factor 2.5 to convert the normal and extreme values to the Dines standard (Bell 1961). The history of the Royal Observatory anemometers and the relevance of the Heywood factor to tropical cyclone extremes has been discussed by Bell (1961) who compared the Dines and cup extremes in four tropical cyclones. Mackey (1971) extended this analysis using all monthly extremes in the four-year period 1935-1938. This paper is a further attempt to standardize the historical records in tropical cyclone conditions and hence to revise the official list of tropical cyclones that have caused gales in Hong Kong.

There was little change in the exposure of the anemometer at the Royal Observatory before 1958 after which tall buildings began to shelter the site. Significantly fewer gales have been recorded since 1958 although many tropical cyclones have come close to Hong Kong. It was decided that wind records at Waglan Island (Figure 1), where the exposure of the anemometer has remained practically unchanged since 1953, should form the basis for listing gales in Hong Kong. A list of tropical cyclone gales at Waglan Island for 1953-1980 has therefore been prepared (see Table 3).

2. STANDARDIZATION OF BECKLEY ANEMOGRAPH RECORDS FOR 1884-1934

Bell (1961) gave an account of the history of wind observations at the Royal Observatory and pointed out the need to standardize the pre-war records. The following is a summary of the historical background.

From 1884-1938 winds at the Royal Observatory were measured with a Beckley Robinson-type cup anemometer and wind speeds in miles per hour were published after multiplying the 'run of the cup' by a factor of 3.0. In the Observatory's Meteorological Results for 1908 it was stated "Robinson's original factor is now known to be too large, but it is retained for the present to avoid confusion in comparison with other records". The statement "For the sake of continuity, Dr. Robinson's factor of 3.0 has been retained for converting the velocity of the cups into wind velocity" appears in every annual volume of Meteorological Results up to the year 1934. In May 1910 a Dines-Baxendall Pressure Tube Anemometer was installed. Comparisons between the records of the two anemometers commenced and results from the years 1910-1916 showed that the annual mean factor (Dines ÷ Beckley/3) varied from 2.11 to 2.42 (Claxton 1917a). Beginning with the year 1916, the mean daily and hourly values of the meteorological elements were also published in c.g.s. units. It was declared that the wind components and velocity had been multiplied by 2.2/3.0 before converting them into c.g.s. units, in order to reduce them to the International Standard (Claxton 1917b). This practice continued until 1938. However, efforts in calculating the 'factor' were maintained throughout the years.

A list of typhoon gales first appeared in 'Hong Kong Meteorological Records 1884-1933', an appendix to Meteorological Results 1933. Robinson's factor of 3 was retained in this list for the sake of uniformity. In 1939, after more than 28 years of comparisons between the Beckley and the Dines-Baxendall anemometers, the factor 2.2 adopted by the Meteorological Office in the United Kingdom, was accepted for conversion of the Beckley values in Hong Kong. The list of typhoon gales was revised and published in the supplement to Meteorological Results 1938.

Unfortunately, the results of the 28 years of comparisons were heavily biassed towards the relatively lighter winds which occur most frequently. In order to convert higher Beckley wind speeds a different conversion factor is needed. Heywood (1939), Bell (1961) and Mackey (1971) have all found that the factor 2.2 is inaccurate in tropical cyclone situations. Hourly wind data from the Dines anemometer for the years 1910-1934 are unfortunately not available as they were probably lost during the war. Only monthly maximum gusts and mean speeds were tabulated in the Meteorological Results. For the years 1935-1938, simultaneous records from the Beckley and Dines anemographs are available. To convert the higher wind speeds from the Beckley anemograph to the Dines standard, the following method has therefore been used :-

During the approach of tropical cyclones in 1935-1938, all hourly mean wind speeds $\geqslant$ 25 miles per hour (22 knots) recorded by the Dines anemometer and the corresponding wind speeds from the Beckley anemometer were extracted. There was a total of 136 hours from 12 tropical cyclones.

These were :

17-18 Sep 1935	21 hours	4 Jul 1937	2 hours
7-8 Oct 1935	27 hours	19-21 Aug 1937	15 hours
18-20 Jul 1936	12 hours	28 Aug 1937	2 hours
13 Aug 1936	11 hours	2 Sep 1937	9 hours
16-17 Aug 1936	13 hours	4 Oct 1937	7 hours
5 Sep 1936	4 hours	3 May 1938	13 hours

Figure 2 shows a plot of these points. A linear regression equation was fitted to all the 136 points with the following result :

$$D = 0.777\ B + 0.103 \qquad \text{.................................} \quad (1)$$

where D = published wind speed from Dines anemometer in mph

B = published wind speed from Beckley anemometer in mph (i.e. the 'run of the cup' x 3.0)

$r = 0.98$

This reduces to a factor of 2.33, which is an intermediate value between the conventional factor of 2.2 and the 2.5 used by Bell (1961) and Heywood and the 2.4 suggested by Mackey (1971) (see Table 1).

TABLE 1. COMPARISON OF CONVERSION FACTORS - BECKLEY TO DINES ANEMOMETERS

	factor into mph	factor into knots
Meteorological Results	2.2/3.0	$B \times \frac{2.2}{3.0} \times \frac{1}{1.15} = 0.6376\ B$
Heywood's factor, also used by Bell (1961)	2.5/3.0	$B \times \frac{2.5}{3.0} \times \frac{1}{1.15} = 0.7246\ B$
Mackey's	2.4/3.0	0.723 B - 1.6
Regression equation	2.33/3.0	0.6761 B + 0.1

With D in knots, equation (1) becomes

$$D = 0.6761\ B + 0.1 \qquad \text{.................................} \quad (2)$$

From the above equation, a wind speed of 50 mph published in the Meteorological Results 1884-1934 is taken to be equivalent to 34 knots. The duration of gales in hours is hence a count of the hourly observations with mean wind speed of 50 mph or more. From 1911 onwards, records of maximum gust peak speeds were available from the Dines anemograph and these are tabulated without any corrections.

For the readers of the pre-war Meteorological Results, it is proposed that, in converting Beckley values into Dines standard in knots, the following can be used :

$D = 0.6761\,B + 0.1$	for	$B \geqslant 32$
$D = 0.6622\,B$		$31 \geqslant B \geqslant 21$
$D = 0.6376\,B$		$B \leqslant 20$

The conventional factor of 2.2 is retained for Beckley speeds of 20 mph or less. For Beckley speeds between 21 and 31 mph the coefficient is derived by linear interpolation thus :

$$0.6376 + \frac{(0.6761 - 0.6376)}{(35 - 10)} \times (26 - 10) = 0.6622$$

3. LIST OF TROPICAL CYCLONES CAUSING PERSISTENT GALES AT THE ROYAL OBSERVATORY 1884 - 1957

With the standardization of historical records, there are 11 additions to the list of tropical cyclones that have caused 'gale force' winds. The dates of their nearest approaches are as follows :

20 Jul 1887	6 Oct 1908
15 Aug 1887	31 Jul 1920
11 Sep 1887	24 Jul 1921
28 Sep 1888	3 Sep 1921
28 Jul 1898	12 Jul 1922
20 Aug 1900	

The new version of the list is at Table 2.

There are also more hours of gales than in the previous lists. The annual totals are shown in Figure 4.

4. VARIATIONS IN GUSTINESS FACTORS DUE TO SITE

Chin and Leong (1978) have discussed the effects of exposure and height on wind measurements at the Royal Observatory. Mean wind speeds and the duration of strong winds were both found to have dropped since the late 1950's.

Another way of illustrating the phenomenon is by the 'gustiness factor'. The gustiness factor is defined as the ratio of the maximum gust to the sustained wind over the same interval of time. Figure 3 is a plot of the annual mean gustiness factors in strong winds at the Royal Observatory and at Waglan Island. Hourly mean winds centred on the hour are used in the analysis. The figure indicates a sharp rise in the gustiness factor at the Royal Observatory around 1957 while that for Waglan Island has remained quite steady. The slight dip in Waglan's gustiness factor in the second half of the record is probably due to the removal of the anemometer from the meteorological station (70.1 m) to the marine signal tower (68.3 m) in January 1964.

Atkinson (1974) studied gustiness factors in tropical cyclones over open water and derived the following relationship :

Peak Gust = 1.40 times ten-minute wind speed

Table 4 is a list of the peak gusts and gustiness factors in major tropical cyclones at various stations in Hong Kong since 1947. Ten-minute mean winds centred on the time of the peak gust were used in this analysis. It can readily be seen that the gustiness factors at Waglan Island are close to Atkinson's. Cheung Chau and Cape Collinson have higher gustiness factors. Factors at Hong Kong Airport and the Royal Observatory are comparable as both anemometer sites are seriously affected by urbanization, and values are much higher than those over open water.

5. LIST OF TROPICAL CYCLONES THAT CAUSED PERSISTENT GALES NEAR SEA LEVEL AT WAGLAN ISLAND 1953 - 1980

Chin and Leong (1978) proposed that hourly mean wind speeds of 28, 39, and 68 knots recorded by the Waglan Island anemometer be used as equivalent to strong, gale and hurricane force winds respectively near sea level. Hourly wind data from Waglan Island were not published until 1975. For the years 1953-1974, hourly mean winds centred on the hour were extracted during all the tropical cyclones that came near Hong Kong. They are listed in Table 3 and the annual total number of hours with gales near sea level is shown in Figure 4.

6. TRACKS OF TROPICAL CYCLONES THAT CAUSED PERSISTENT GALES AT THE ROYAL OBSERVATORY AND AT WAGLAN ISLAND

Tracks of the tropical cyclones that caused persistent gales are illustrated in Figures 5 and 6. The black dots and asterisks on the tracks mark the tropical cyclone positions at the times of onset and cessation respectively of gales in Hong Kong. Tracks are grouped into months according to the dates of occurrence of minimum pressure as shown in Tables 2 and 3.

7. CONCLUSIONS

A method has been devised to standardize the 1884-1934 Beckley anemograph records at the Royal Observatory during tropical cyclone situations. A wind speed of 50 mph published in the Meteorological Results, 1884-1934, has been found to be equivalent to 34 knots. The official list of tropical cyclones that have caused gales in Hong Kong has therefore been revised.

After 1958, tall buildings began to shelter the site of the Royal Observatory from strong winds. It was therefore decided that wind records from Waglan Island, where the exposure of the anemometer has remained practically unchanged since 1953, should form the basis for listing gales in Hong Kong. Hourly mean wind speeds of 39 knots on the top of the signal tower at Waglan Island, are taken as the equivalent to gale force winds near sea level. The tables that follow give a revised historical summary of all the tropical cyclones that are considered to have caused persistent gales in Hong Kong and a summary of the winds associated with each of them.

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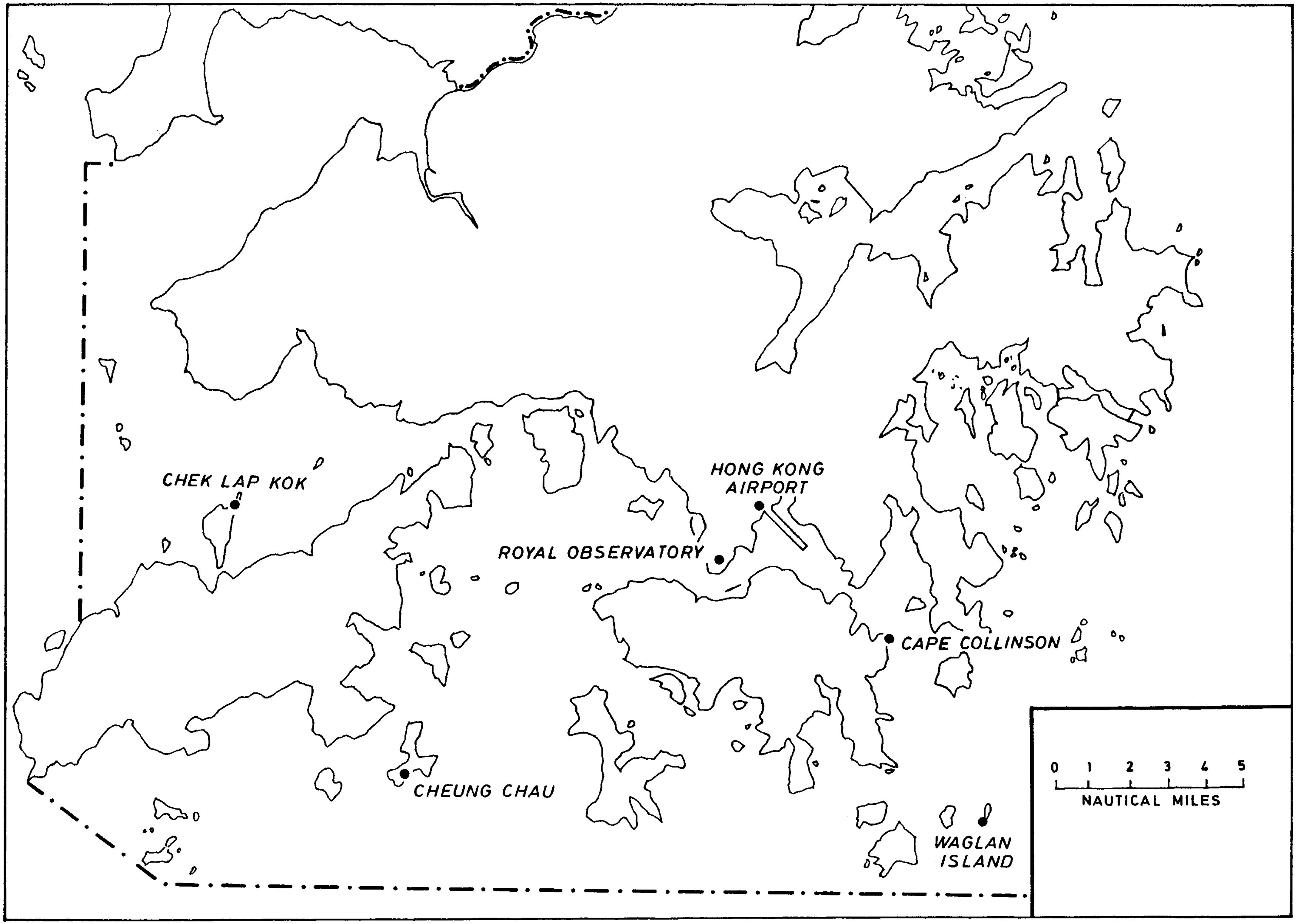


Figure 1. Location map of the meteorological stations.

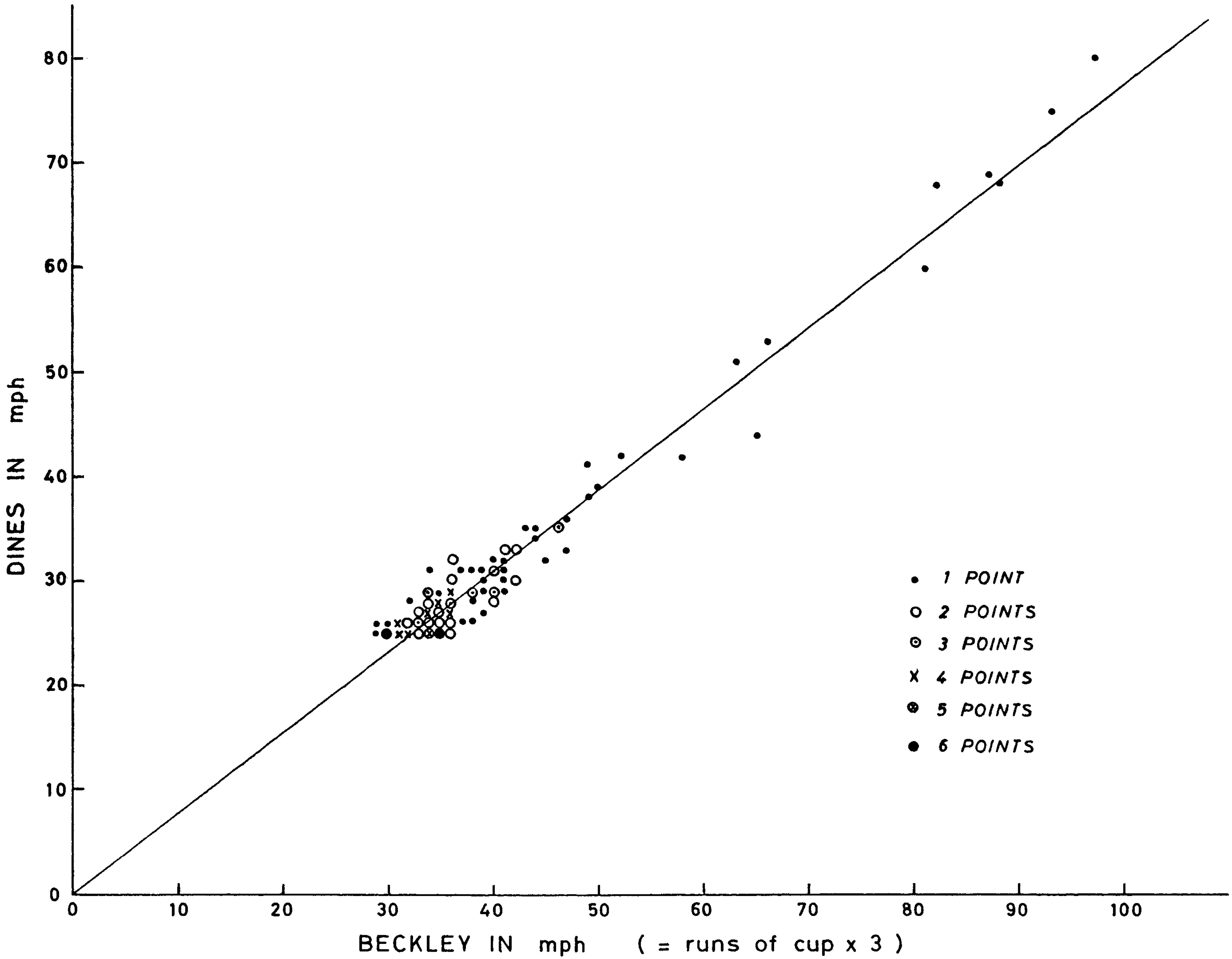


Figure 2. Hours of strong winds at the Royal Observatory during approach of tropical cyclones, 1935-1938
Dines against Beckley in mph.

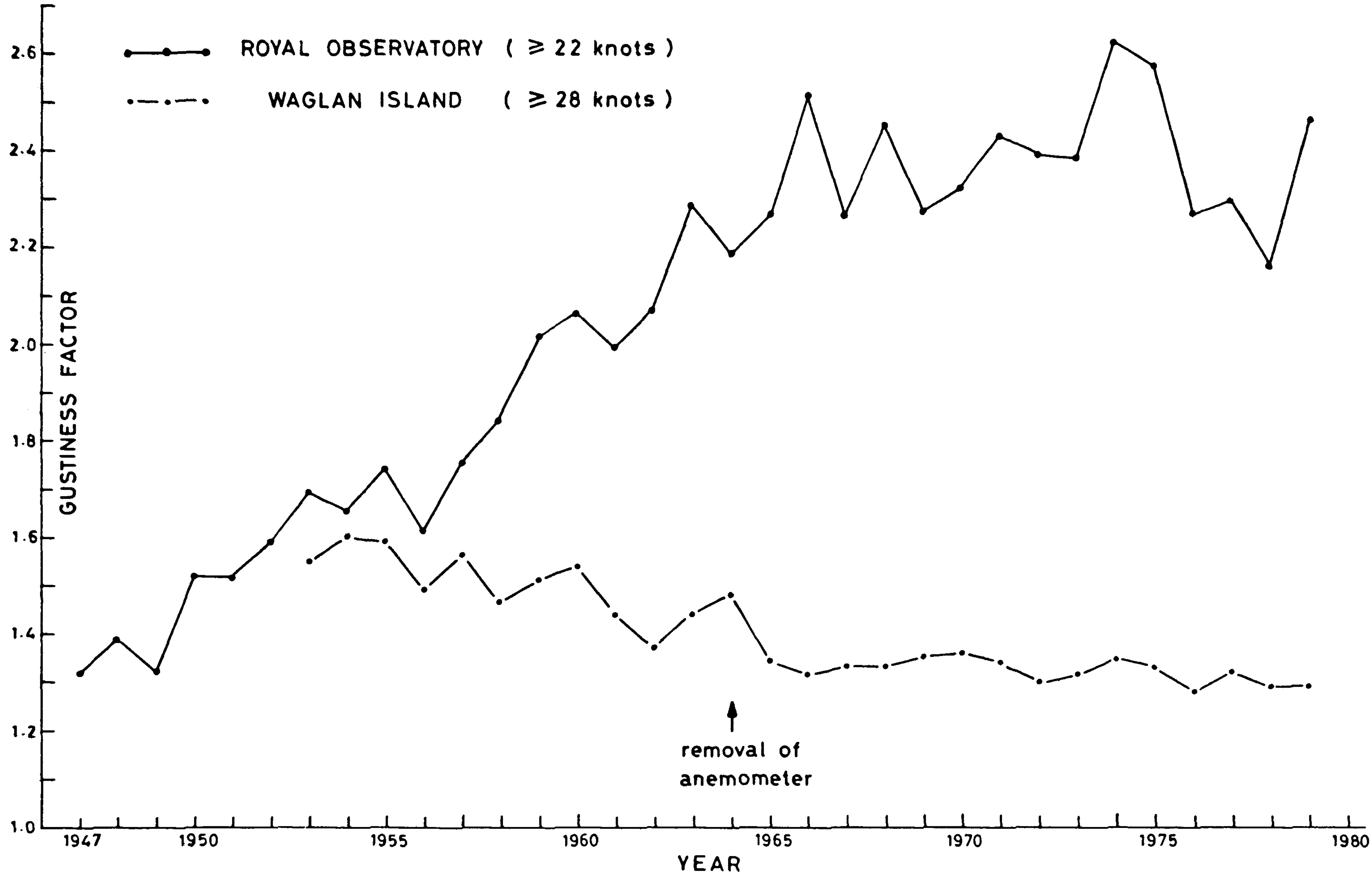


Figure 3. Annual mean gustiness factors in strong winds.

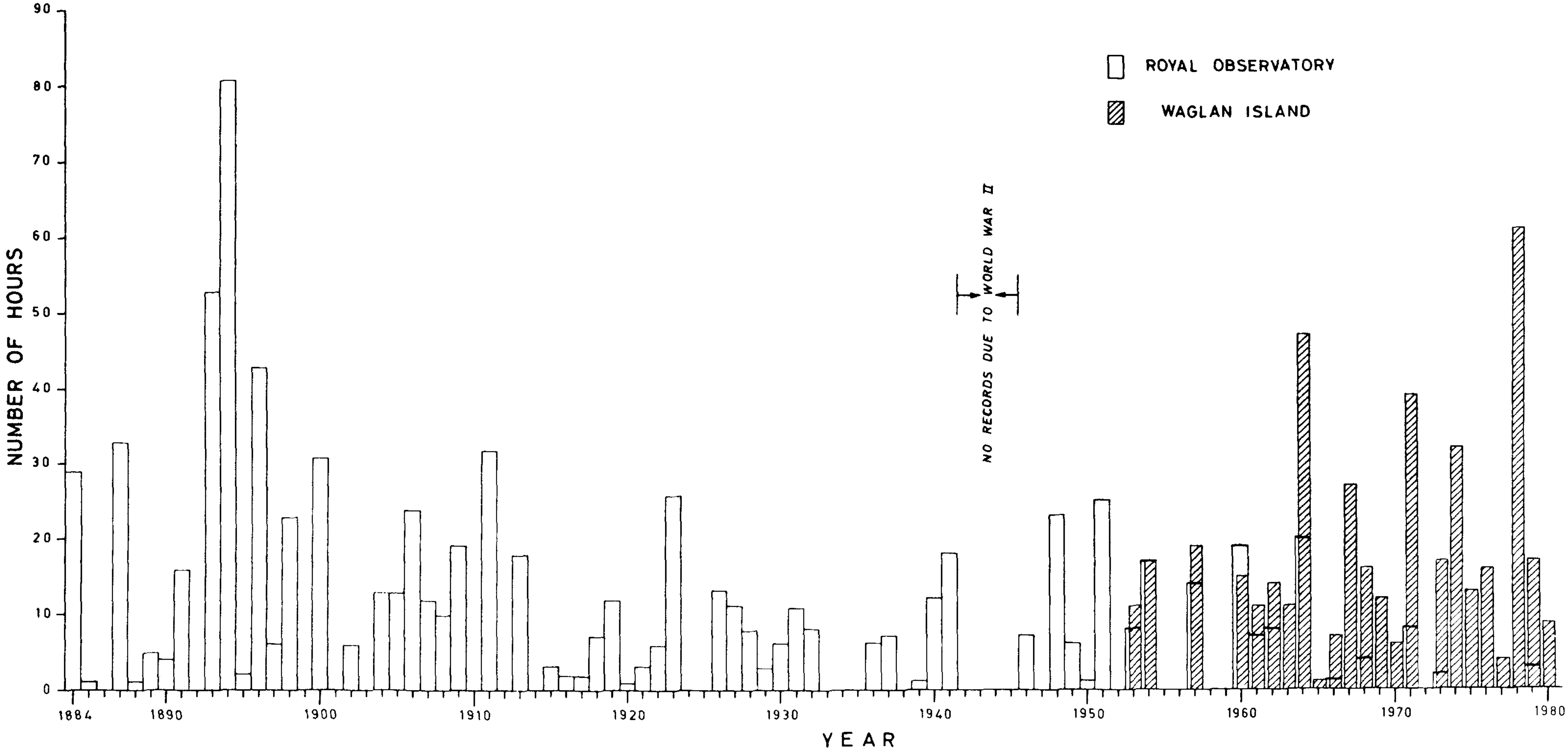


Figure 4. Annual total number of hours with tropical cyclone gales at the Royal Observatory 1884-1980 & at Waglan Island 1953-1980.

TABLE 2. TROPICAL CYCLONES CAUSING PERSISTENT GALES AT THE ROYAL OBSERVATORY

1884 - 1957

Name of Tropical Cyclone	Date and Time of Occurrence of Minimum Pressure		Nearest Approach		Maximum Mean Hourly Wind		Maximum Gust Peak Speed (kn)	Duration of Gales (h)	Sequence of Wind Direction	Minimum Pressure (millibars)		Remarks
	Date	Hour H.K. Time	bearing	Distance (n mile)	Direction	Speed (kn)				Hourly Reading	Instantaneous Minimum	
	1884 July 29	0300	S	180	E/S	37		12	ENE to ESE v	997.5		
	September 11	0200	WSW	57	ENE	60		17	N/E to SSE v	979.8	979.4	
	1885 August 17	1400	SSW	43	ESE	36		1	E to S/E v	997.8		
	1887 July 20	0400	S	72	ESE	34		1	NE to ESE v	993.1		
	August 15	1600	SSW	167	ESE	35		3	ENE to ESE v	1002.8		
	September 11	2300	N	31	W	35		1	NW to S .... b	986.3		
	September 17	1700	SW	85	E/S	47		16	NE to SE v	999.3		
	September 21	0400	SSW	258	E	38		7	ENE to SE/E v	1000.6		
	September 25	1400	S	176	E	37		5	ENE to ESE v	1000.4		
	1888 September 28	1500	S	246	ENE	34		1	N to NE v	1000.2		
	1889 October 16	0400	ENE	32	W/N	41		5	NW/N to W ...... b	997.0		
	1890 October 13	0400	S	126	NE/E	36		4	NE to ENE v	1006.4		
	1891 July 19	0500	NNE	13	SSW	43		5	NW/W to SSW .... b	980.9	980.8	
	August 3	0400	SSW	35	ESE	41		11	NNE to SE v	990.7		
	1893 September 9	0300	E	67	NW	40		4	NNW to NW/W .... b	983.2		
	September 28	1600	S	162	E/N	41		17	NE/E to E/N v	999.3	999.1	
	October 2	1400	SSW	86	E	55		26	NNE to SE v	991.8		
	October 8	0400	S	78	E/N	39		6	N/E to ESE v	1000.7		
	1894 September 19	0300	SSW	180	E/S	45		21	NE/E to SE v	995.4		
	September 25	0900	SSW	51	E/N	58		10	NE to SE v	994.5		
	September 30	0600	SSW	172	E	43		21	NE/N to SE/E ... v	999.6		
	October 5	1700	WNW	40	SE/S	58		29	NE/E to SW/S ... v	987.0		
	1895 July 28	1600	SSW	73	NE/E	36		2	NE/N to E/S v	995.1		Centre recurved around Hong Kong.
	1896 July 29	2200	SSW	22	E/S	73		10	NNE to S/E v	976.6	975.8	Highest hourly wind velocity.
	August 9	1600	S	128	ENE	45		11	NE/E to SE/E ... v	997.8	997.8	
	October 6	0400	SSW	131	E/N	45		22	NE/E to SE v	996.4	996.4	
	1897 September 17	1500	SSW	202	NE/E	38		6	NE/E to ENE v	1004.6		
	1898 July 28	1700	SSW	156	E	34		2	NE to ESE v	995.6		
	August 5	0300	SSW	55	E	42		11	ENE to SE v	987.1		
	August 17	1700	SSW	112	E	41		10	ENE to SE v	995.8		
	1900 August 20	1500	S	162	ENE	35		3	NE to E v	993.6		
	September 11	0500	SSW	124	E	46		16	NE/E to SE v	996.6		
	November 10	0600	SW	8	NNE	61		12	NE/E to SW/W ... b	975.0		

TABLE 2. TROPICAL CYCLONES CAUSING PERSISTENT GALES AT THE ROYAL OBSERVATORY (Cont'd)

1884 - 1957

Name of Tropical Cyclone	Date and Time of Occurrence of Minimum Pressure: Date	Hour H.K. Time	Nearest Approach: bearing	Distance (n mile)	Maximum Mean Hourly Wind: Direction	Speed (kn)	Maximum Gust Peak Speed (kn)	Duration of Gales (h)	Sequence of Wind Direction	Minimum Pressure (millibars): Hourly Reading	Instantaneous Minimum	Remarks
	1902 July 18	1600	E	10	SW/S	41		3	N to SW/S ...... b	984.4		
	August 2	2000	NNE	51	SW/S	56		3	NW/W to SW/S ... b	986.9		
	1904 August 10	0200	SSE	59	E/S	36		4	E to ESE v	998.1		
	August 25	1700	S	48	E/N	38		9	E/N to NNE ..... b	986.8		
	1905 August 30	1500	S	90	ENE	44		13	N/E to E/N v	988.2		
	1906 September 18	1000	SE	5	SSW	52		3	NW to S .... b	986.2		
	September 20	0400	S	120	E/S	39		5	ENE to ESE v	1000.5		
	September 29	0900	SSW	90	E/N	53		16	NNE to SE v	993.9		
	1907 September 14	0100	SSW	46	E/S	51		12	NE/N to SE v	993.3		
	1908 July 28	0100	W	6	SSE	55		5	N to S/E v	978.0		Centre passed over Cheung Chau.
	October 6	0400	SSW	212	E	34		2	NE to ESE v	1005.5		
	October 11	0100	SSW	148	E/S	36		3	NE/E to E/N v	1003.6		
	1909 October 19	1700	SW	50	ESE	51		15	NNE to SE v	987.4		
	October 25	1700	SW	145	E	37		4	NE to SE v	1003.6		
	1911 July 4	0300	SW	142	ESE	39	63	9	ENE to SE v	996.9		Dines anemograph installed in 1911.
	July 27	1000	SSW	15	ESE	41	64	5	N to SSE v	988.2		
	August 5	0900	WSW	48	S/E	42	69	18	ENE to SSE v	991.1		
	1913 August 17	1100	SSW	35	ENE	58	91	13	NE/E to SE/E ... v	991.1		
	September 18	2300	NE	76	SW/W	38	61	5	WNW to SSW ..... b	992.2		
	1915 November 5	1600	SW	115	E	38	60	3	NE/E to SE v	1002.3		
	1916 September 7	0200	S	140	E	37	56	2	ENE to SE/E v	999.1		
	1917 August 13	1100	N	6	SSW	43	81	2	backed from NW b	986.6		Centre passed a few miles to N'ward.
	1918 August 15	0800	SW	30	E/N	43	82	7	NE/E to S/E v	987.7		
	1919 August 22	1600	SSW	164	E/S	41	73	12	E/N to SE/E v	999.2		
	1920 July 31	0500	SW	106	E	35	53	1	NE to ESE v	996.9		
	1921 July 24	0400	S	120	E	35	-	1	NE to ESE v	994.8		
	September 3	1500	SW	112	E	34	60	2	ENE to SE v	1001.2		
	1922 July 12	1500	WSW	84	E	35	61	1	NE to SE v	999.8		
	September 20	1700	SW	187	ENE	37	65	5	NE/E to E/S v	999.8		
	1923 July 2	0500	SSW	81	E/S	42	-	9	ENE to S/E v	990.8		
	July 22	1700	SW	103	ESE	43	76	13	E/N to S/E v	988.7		
	July 27	1000	NE	10	S/W	41	-	1	SW/S to S/W .... b	983.1		
	August 18	1000	S	6	NNE	72	113*	3	N/W to ESE v	971.7		Centre passed a few miles to S'ward.
	1926 July 22	0900	S	35	N/E	41	74	5	NE/N to ESE v	991.7		
	September 27	0600	S	50	E/N	49	88	8	N to ESE v	991.8		
	1927 August 20	1400	S	60	NE/E	56	101	11	NNE to SE v	982.4		
	1928 July 15	0100	S	108	E	40	66	8	NE/E to SE/E ... v	992.7		
	1929 August 22	1400	S	6	SE	60	102	3	NNE to S/E v	983.2		
	1930 July 24	1800	WSW	54	E	45	72	6	NE/N to ESE v	990.9		

TABLE 2. TROPICAL CYCLONES CAUSING PERSISTENT GALES AT THE ROYAL OBSERVATORY (Cont'd)

1884 - 1957

Name of Tropical Cyclone	Date and Time of Occurrence of Minimum Pressure		Nearest Approach		Maximum Mean Hourly Wind		Maximum Gust Peak Speed (kn)	Duration of Gales (h)	Sequence of Wind Direction	Minimum Pressure (millibars)		Remarks
	Date	Hour H.K. Time	bearing	Distance (n mile)	Direction	Speed (kn)				Hourly Reading	Instantaneous Minimum	
	1931 August 1	1200	S	30	E/N	64	118*	5	NE to ESE v	989.2		
	September 2	1500	-	0	S/E	44	82	6	NE/N to S/E v	988.7		
	1932 September 17	0500	S	192	NE/E	37	69	8	NE/E to ESE v	996.1		
	1936 August 17	0300	SSW	35	E/N	70	115*	6	NE/E to SE/S ... v	979.3		
	1937 September 2	0400	SSW	5	NE/E	65	130*	7	NNW to SE/S v	958.3		Max. gust peak speed 145 kn at North Point
	1939 November 23	1600	SSE	35	E/N	35	64	1	E to NW v	989.5		
	1940 August 21	0900	SSE	19	E	45	72	12	NNW to E/S v	990.2		
	1941 June 30	1600	SSW	55	ENE	44	83	9	NE to E v	977.8		
	September 16	1200	NE	25	E/N	55	94	9	N to S/E v	983.7		
	1942 - 1945				No records due to World War II			(No very severe typhoons)				Severest typhoon during the period on July 22, 1944.
	1946 July 18	1600	S	37	N/E	-	95	7	N to S v	985.7		
	1948 June 10	1200	SSW	25	E	39	48	1	NE to ESE v	993.1	992.9	
	July 27	1700	E	24	SSW	45	64	8	NNE to SW ...... b	981.1	980.1	
	September 3	0400	SSW	112	E	46	75	14	NE to ESE v	996.3	995.5	
	1949 September 8	0300	S	37	E	56	81	6	N to SE v	991.3	990.8	
	1950 October 5	0400	SSW	65	E	34	59	1	N to ENE v	997.3	997.2	
	1951 June 18	1800	SW	192	E	36	63	2	ENE to ESE v	1001.7	1001.6	
	August 1	1800	SW	82	ENE	44	76	19	ENE to ESE v	990.8	990.1	
	September 2	1400	S	198	ENE	36	59	4	ENE to E v	1002.9	1002.4	
Typhoon Susan	1953 September 18	1800	SSW	42	NE	42	75	8	N to ESE v	995.0	994.7	
Typhoon Ida	1954 August 29	1400	SSW	78	ENE	47	87	12	NNE to ESE v	992.9	992.4	
Typhoon Pamela	November 6	1100	SW	31	E	47	84	5	NNE to SE v	997.6	997.1	
Typhoon Gloria	1957 September 22	1700	SW	30	ENE	59	101	14	N to SE v	986.2	984.3	

Note : No corrections for air-density have been made to the wind speeds in this table

* Estimated

v = veering

b = backing

TABLE 3. TROPICAL CYCLONES CAUSING PERSISTENT GALES NEAR SEA LEVEL AT WAGLAN ISLAND
1953 - 1980

Name of Tropical Cyclone	Date and Time of Occurrence of Minimum Pressure at Waglan Island		Nearest Approach				Maximum 60-min mean wind		Maximum Gust Peak Speed				Duration of Gales (h)	Sequence of Wind Direction	Minimum Pressure (millibars)			Remarks
			to Royal Observatory		to Waglan Island				at Waglan Island		at Royal Observatory				at Royal Observatory		at Waglan Island	
	Date	Hour H.K. Time	bearing	distance (n mile)	bearing	distance (n mile)	Direction	Speed (kn)	Direction	Speed (kn)	Direction	Speed (kn)			Hourly Reading	Instantaneous Minimum	Instantaneous Minimum	
T. Susan	1953 September 18	1700	SSW	42	SSW	36	NNE	60	ENE	93	NNE	75	11	N to ESE....v	995.0	994.7	990.3	
T. Ida	1954 August 29	1600	SSW	78	SSW	72	ENE	50	ENE	94	ENE	87	10	NNE to ESE..v	992.9	992.4	991.1	
T. Pamela	1954 November 6	1100	SW	31	SW	26	E	61	E	94	ENE	84	7	N to ESE....v	997.6	997.1	989.0	
T. Wendy	1957 July 16	2000	NE	25	NE	32	S	44	S	71	SSW	71	3	N to S......b	988.3	988.3	986.8	
T. Gloria	1957 September 22	1600	SW	30	SW	25	E	61	ENE	100	E	101	16	NNE to ESE..v	986.2	984.3	981.9	
T. Mary	1960 June 9	0500	WNW	5	WNW	13	SSW	60	SSW	105	SSE	103	15	ESE to WSW..v	974.3	973.8	976.1	Centre passed over Cheung Chau
T. Alice	1961 May 19	1200		0	WNW	7	ESE	49	SW	69	E	89	8	E to SW.....v	981.6	981.1	980.0	Centre passed over Observatory
S.T.S. Olga	1961 September 10	0100	NE	30	NE	32	W	43	W	65	WNW	64	3	NNW to SW...b	986.5	986.1	985.0	
T. Wanda	1962 September 1	0800	SSW	10	S	3	NW	80	NNW	117	N	140	14	NNE to SSE..v	955.1	953.2	944.0*	Max. gust peak speed at Tate's Cairn 154 kn
T. Faye	1963 September 6	1700	S	126	S	118	NE	46	NE	63	ENE	70	11	NNE to ESE..v	996.4	996.1	995.9	
T. Viola	1964 May 28	0800	WSW	50	WSW	51	E	49	SSE	76	E	82	7	E to SSW....v	993.0	991.9	992.4	
T. Ida	1964 August 8	2300	SW	32	SW	27	SSE	68	ENE	100	NE	112	12	N to S......v	972.3	972.0	971.5	
T. Ruby	1964 September 5	1200	SW	17	WSW	16	ENE	80	E	124	NNE	122	11	N to SSE....v	971.0	968.2	960.0	
T. Dot	1964 October 13	0500	E	18	E	13	N	63	N	99	N	94	17	ENE to WSW..b	978.9	977.3	974.0	
T. Freda	1965 July 14	1900	SW	133	SW	126	E	39	E	71	ESE	61	1	NE to SE....v	996.0	995.8	994.1	
S.T.S. Lola	1966 July 13	1900	S	13	SW	8	ENE	50	E	71	ENE	82	7	NNE to S....v	990.1	989.5	988.6	
S.T.S. Kate	1967 August 21	1700	SW	54	SW	54	ENE	44	ENE	62	E	80	10	ENE to S....v	989.8	989.6	989.6	
T. Carla	1967 October 18	1400	SSW	153	SSW	147	E	47	E	63	ENE	55	13	N to E......v	1006.9	1006.6	1006.8	
T. Emma	1967 November 7	0200	SW	200	SW	191	E	40	E	52	E	51	4	NE to E.....v	1009.3	1008.9	1008.7	
T. Shirley	1968 August 21	1800		0		0	NNE	67	NE	113	N	72	14	NNE to SW...v	968.7	968.6	966.3*	Centre passed over Observatory
S.T.S. Bess	1968 September 3	0500	S	162	S	153	ENE	39	ENE	50	ENE	50	2	ENE to E....v	1002.5	1002.3	1001.3	
T. Viola	1969 July 28	1800	NNE	63	NNE	72	SW	54	SW	74	SW	67	12	N to S......b	982.1	981.9	978.9	

* Hourly reading

TABLE 3. TROPICAL CYCLONES CAUSING PERSISTENT GALES NEAR SEA LEVEL AT WAGLAN ISLAND (Cont'd)
1953 - 1980

Name Tropical Cyclone	Date and Time of Occurrence of Minimum Pressure at Waglan Island		Nearest Approach				Maximum 60-min mean wind		Maximum Gust Peak Speed				Duration of Gales (h)	Sequence of Wind Direction	Minimum Pressure (millibars)			Remarks
			to Royal Observatory		to Waglan Island				at Waglan Island		at Royal Observatory				at Royal Observatory		at Waglan Island	
	Date	Hour H.K. Time	bearing	distance (n mile)	bearing	distance (n mile)	Direction	Speed (kn)	Direction	Speed (kn)	Direction	Speed (kn)			Hourly Reading	Instantaneous Minimum	Instantaneous Minimum	
T.S. Ruby	1970 July 16	0900	E	36	E	33	SW	62	SW	83	SW	69	3	N to SW.....b	993.7	993.6	992.0	
T.D.	1970 August 2	1700	N	54	N	62	SW	40	SW	59	SW	64	2	W to SW.....b	995.7	994.7	994.1	
T. Georgia	1970 September 14	0400	E	63	E	60	NW	40	NW	55	NW	56	1	N to SW.....b	995.3	995.0	991.5	
T. Freda	1971 June 18	0100	SW	22	SW	20	SSE	52	E	69	E	79	17	NE to S.....v	984.4	984.3	979.8	
T. Lucy	1971 July 22	1000	NNE	23	NE	26	SW	55	WSW	80	NW	68	7	NNW to SSE..b	978.2	977.9	974.7	
T. Rose	1971 August 16	2400	WSW	11	W	13	ESE	76	ESE	102	ESE	121	15	NE to S.....v	984.5	982.8	982.6	Centre passed about 5 miles west of Cheung Chau
T. Dot	1973 July 17	0500	E	12	E	7	E	59	E	86	E	77	17	E to W......b	978.3	978.0	975.4	Maximum gust peak speed at Tate's Cairn 97 kn
T. Bess	1974 October 12	1800	S	195	S	185	E	45	E	58	E	50	9	NNE to E....v	1001.8	1001.1	999.5	
T. Carmen	1974 October 19	0500	SSW	66	SSW	60	E	49	E	71	E	70	15	N to SE.....v	994.1	993.7	992.5	
T. Elaine	1974 October 30	0400	S	80	S	72	ENE	44	ENE	55	ENE	52	8	N to E......v	1000.0	999.8	999.0	
T. Elsie	1975 October 14	1300	S	27	S	18	NNE	64	ENE	95	NE	76	11	N to SE.....v	996.4	996.2	987.5	
S.T.S. Flossie	1975 October 23	0100	SW	140	SW	138	ENE	42	ENE	69	NE	67	2	N to E......v	1003.3	1003.1	997.0	
T.S. Ellen	1976 August 24	0600	N	60	N	66	SE	40	S	63	SW	50	1	NW to S.....b	996.3	995.6	994.9	
T. Iris	1976 September 19	0400	SSW	95	SSW	87	ENE	53	ENE	70	ENE	67	15	NE to ESE...v	999.8	999.5	997.3	
S.T.S. Freda	1977 September 24	1700	SSW	80	SSW	73	ENE	46	ENE	65	ENE	55	4	N to ESE....v	1001.1	1000.8	998.7	
S.T.S. Agnes	1978 July 26	1600	SSE	56	SSE	44	E	62	E	76	E	71	23	N to E......v	989.8	989.0	985.2	
S.T.S. Agnes	1978 July 29	2400	E	35	ESE	27	N	47	N	61	ENE	49	9	E to NW.....b	986.6	986.0	981.4	
S.T.S. Elaine	1978 August 27	0600	SW	140	SW	140	ENE	53	ENE	69	E	81	18	NNE to ESE..v	993.0	992.0	991.4	
T. Lola	1978 October 1	0300	SW	240	SW	240	E	40	E	50	E	48	3	NE to ESE...v	1003.3	1003.3	1003.1	
S.T.S. Nina	1978 October 16	1500	SW	170	SW	168	E	46	E	56	ENE	45	8	N to E......v	1009.4	1009.4	1008.5	
T. Hope	1979 August 2	1400	NNW	6	NNW	14	SW	78	SW	107	W	94	6	NW to SE...b	961.8	961.6	964.1	Centre passed over Tai Po Kau and Tuen Mun
S.T.S. Mac	1979 September 23	1400	W	25	W	24	E	66	E	80	ENE	71	11	ENE to SE..v	1001.0	1000.6	998.7	
T. Joe	1980 July 22	0500	SSW	190	SSW	182	ENE	44	E	68	E	58	6	NE to SE...v	1001.2	1000.9	999.2	
T. Kim	1980 July 27	1400	E	100	E	95	SW	44	SW	57	SW	58	3	N to SW....b	998.9	998.9	994.5	

Note : No corrections for air-density have been made to the wind speeds in this table

TABLE 4. PEAK GUSTS AND GUSTINESS FACTORS IN MAJOR TROPICAL CYCLONES AT VARIOUS STATIONS SINCE 1947

Name of Tropical Cyclone	Date			Royal Observatory			Hong Kong Airport			Waglan Island			Cheung Chau			Cape Collinson		
Typhoon	27	Jul	1948	SW	65	1.48	NNW	72	2.40									
T. Gloria	22	Sep	1957	E	101	1.58	ENE	86	2.39	ENE	100	1.56						
T. Mary	9	Jun	1960	SSE	103	1.98	SE	88	1.91	SSW	105	1.67						
T. Alice	19	May	1961	E	89	1.93	ENE	75	1.88	SW	69	1.35	ENE	73	1.78			
T. Wanda	1	Sep	1962	N	140	1.79	N	123	2.05	NNW	117	1.46	NW	125	1.89			
T. Ida	8	Aug	1964	NE	112	2.49	NE	93	1.60	ENE	100	1.33	NNE	88	2.10	ENE	89	1.41
T. Ruby	5	Sep	1964	NNE	122	2.49	NW	110	1.83	E	124	1.49	NNE	117	1.83	S	120	1.30
T. Dot	13	Oct	1964	N	94	1.88	N	107	2.68	N	99	1.48	WNW	111	2.13	NNE	101	1.87
S.T.S. Lola	13	Jul	1966	ENE	82	2.65	N	72	2.12	ENE	71	1.31	S	75	2.68	S	72	1.36
T. Shirley	21	Aug	1968	N	72	2.25	N	82	2.28	NE	113	1.61	SSW	90	1.91	N	93	2.38
T. Freda	18	Jun	1971	E	79	2.14	ENE	80	1.86	E	69	1.21	SSW	82	1.39	SSW	71	1.73
T. Lucy	22	Jul	1971	NW	68	2.52	SW	63	1.91	WSW	80	1.40	NW	70	1.75	NW	72	1.80
T. Rose	17	Aug	1971	ESE	121	2.33	ESE	114	2.28	ESE	102	1.32	SE	105	1.35	S	103	1.32
T. Dot	17	Jul	1973	E	77	2.48	E	81	2.89	ESE	86	1.56	WNW	75	1.42	ENE	74	1.37
T. Carmen	19	Oct	1974	E	70	3.18	NE	60	2.40	E	71	1.48	E	65	1.63			
T. Elsie	14	Oct	1975	NE	76	2.45	N	76	2.00	ENE	95	1.56	NE	86	1.54			
T. Iris	18	Sep	1976	ENE	67	2.16	NE	59	2.27	ENE	70	1.35	E	73	1.74			
S.T.S. Agnes	27	Jul	1978	E	71	2.15	ENE	70	1.67	E	76	1.27	E	73	1.46			
T. Elaine	27	Aug	1978	E	81	2.45	E	78	2.44	ENE	69	1.44	E	83	1.48			
T. Hope	2	Aug	1979	W	94	2.24	WNW	98	1.58	SW	107	1.30	WSW	100	1.56			
S.T.S. Mac	23	Sep	1979	ENE	71	2.54	E	66	1.83	E	80	1.25	ESE	68	1.31			

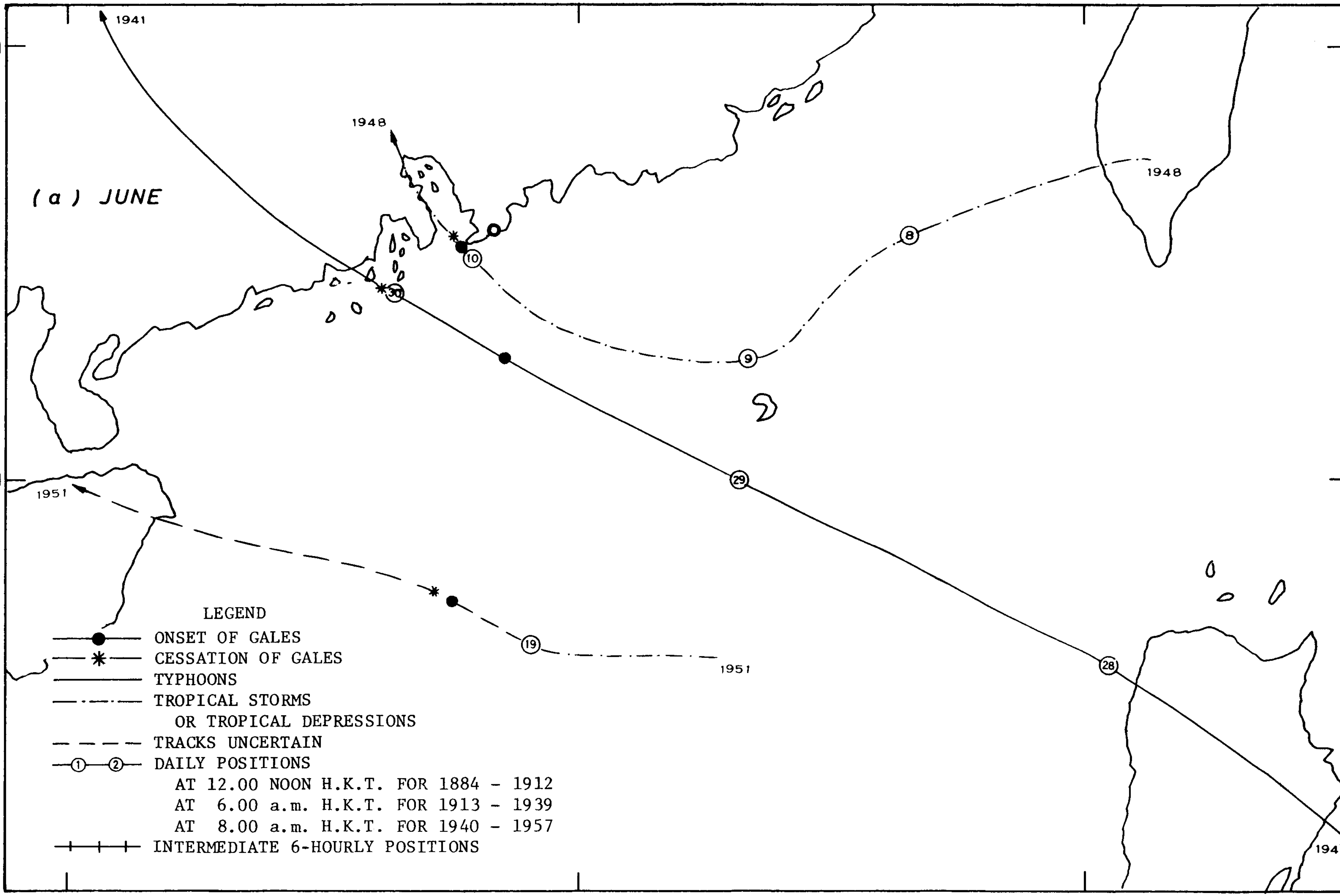


Figure 5. Tracks of tropical cyclones that caused persistent gales at the Royal Observatory 1884 - 1957.

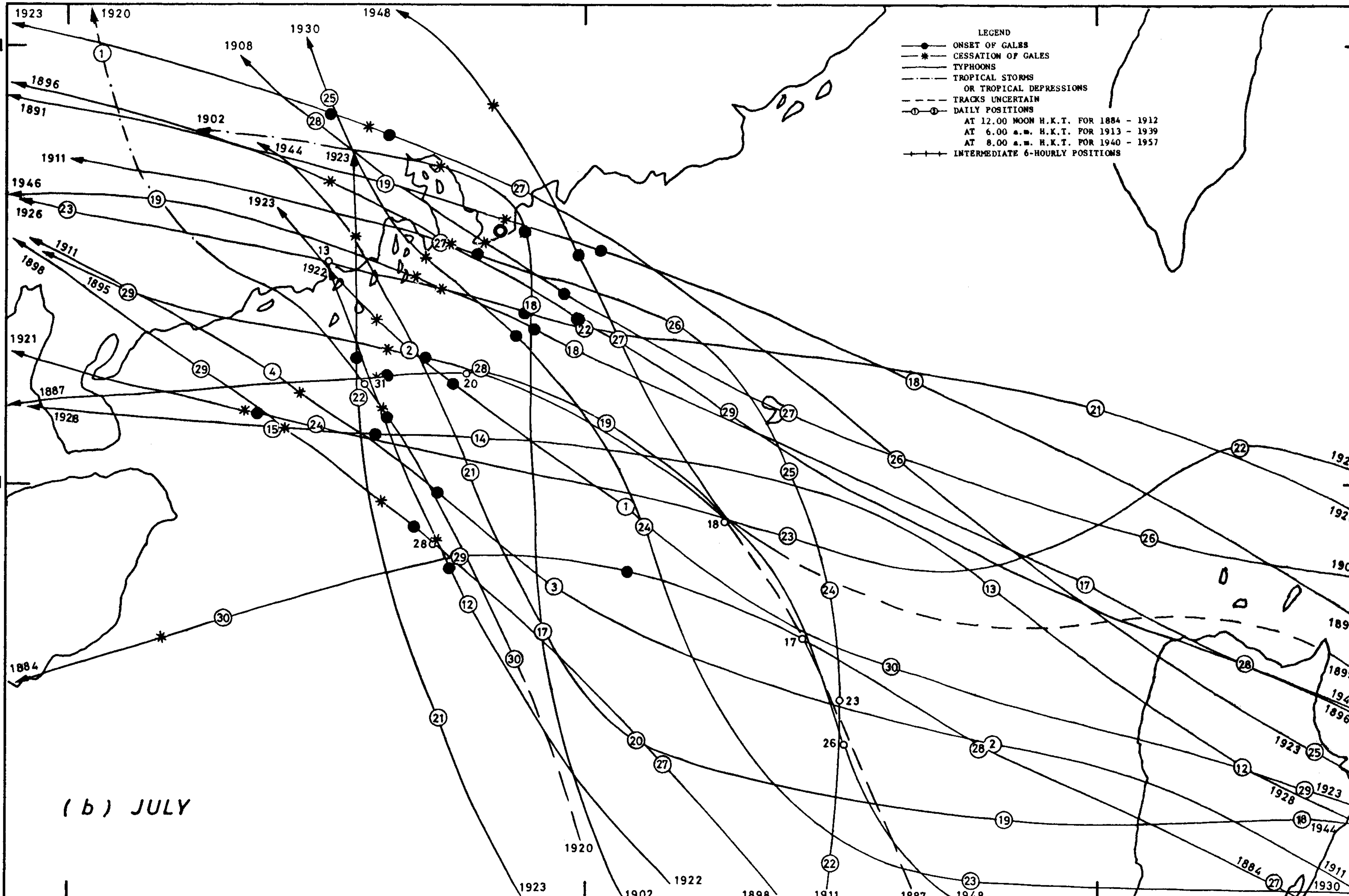


Figure 5. (Cont'd)

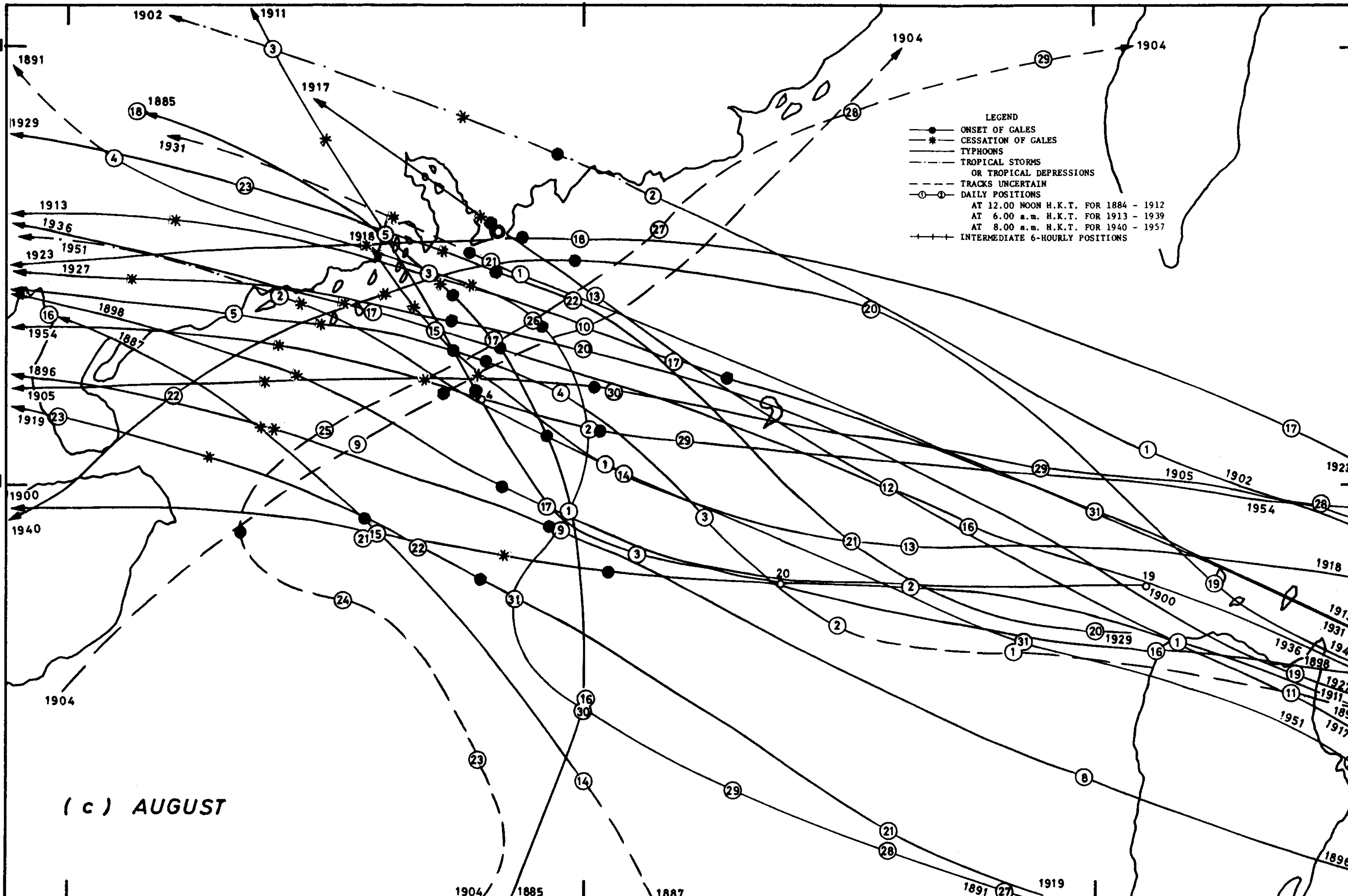


Figure 5. (Cont'd)

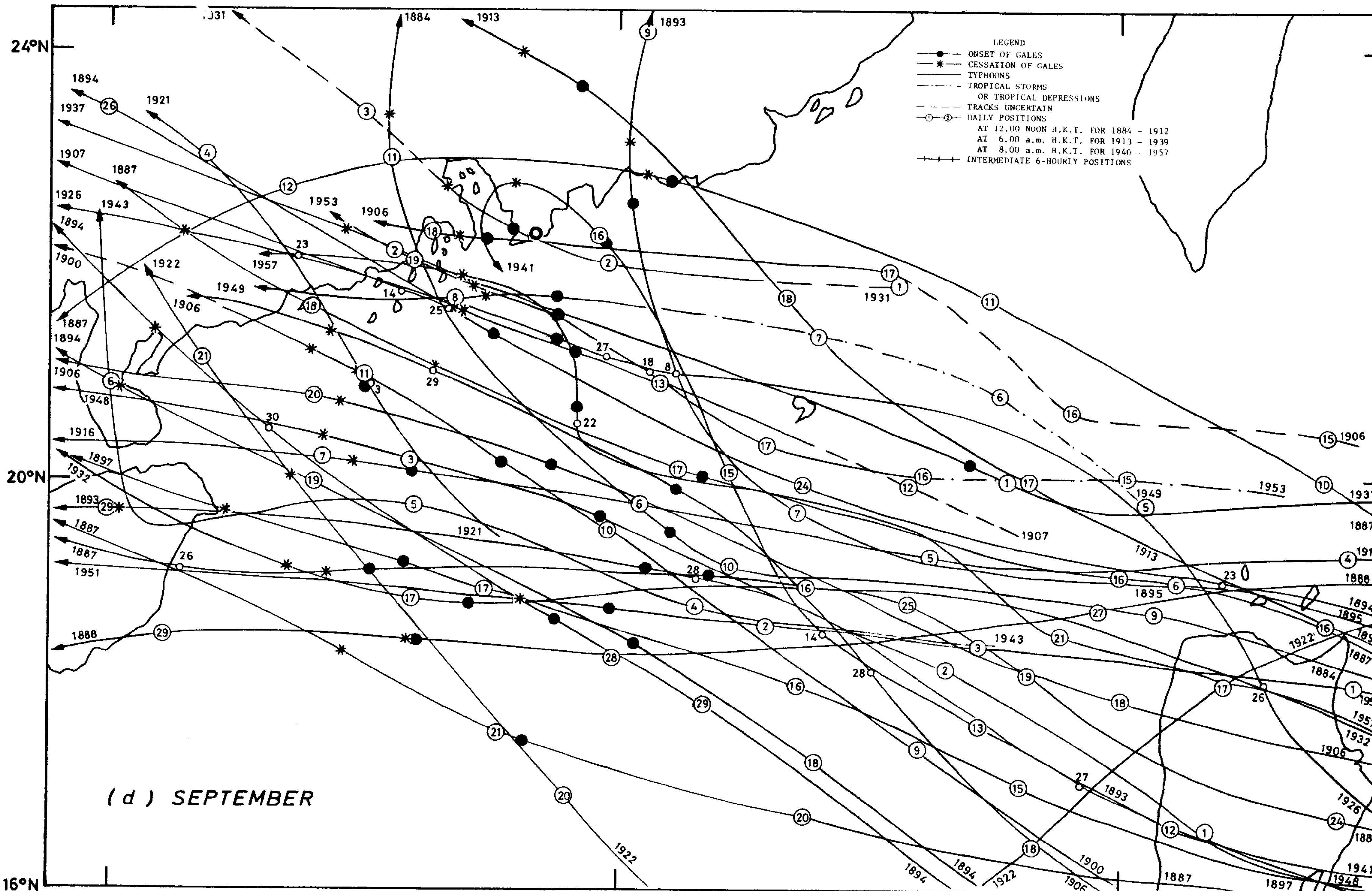
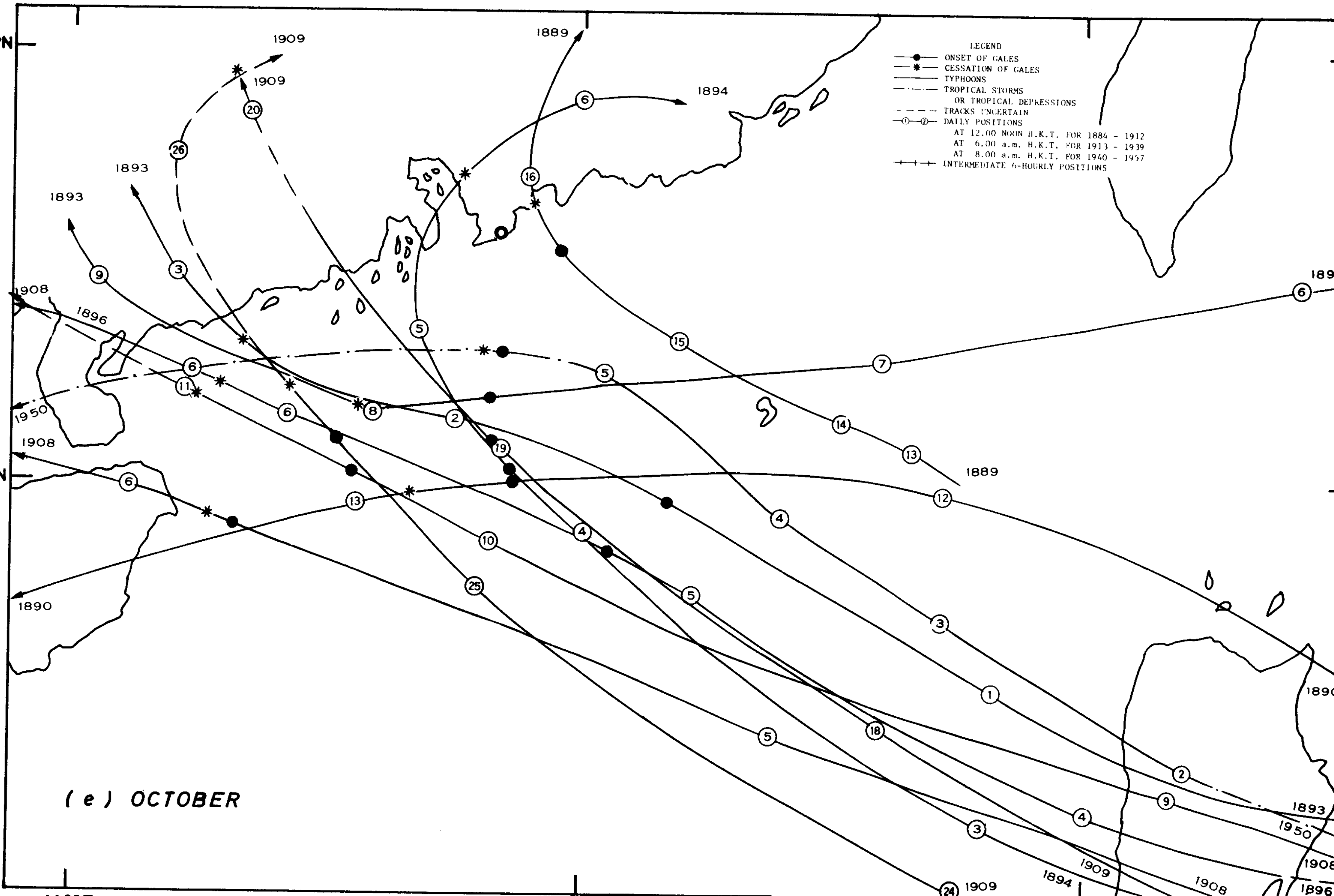


Figure 5. (Cont'd)



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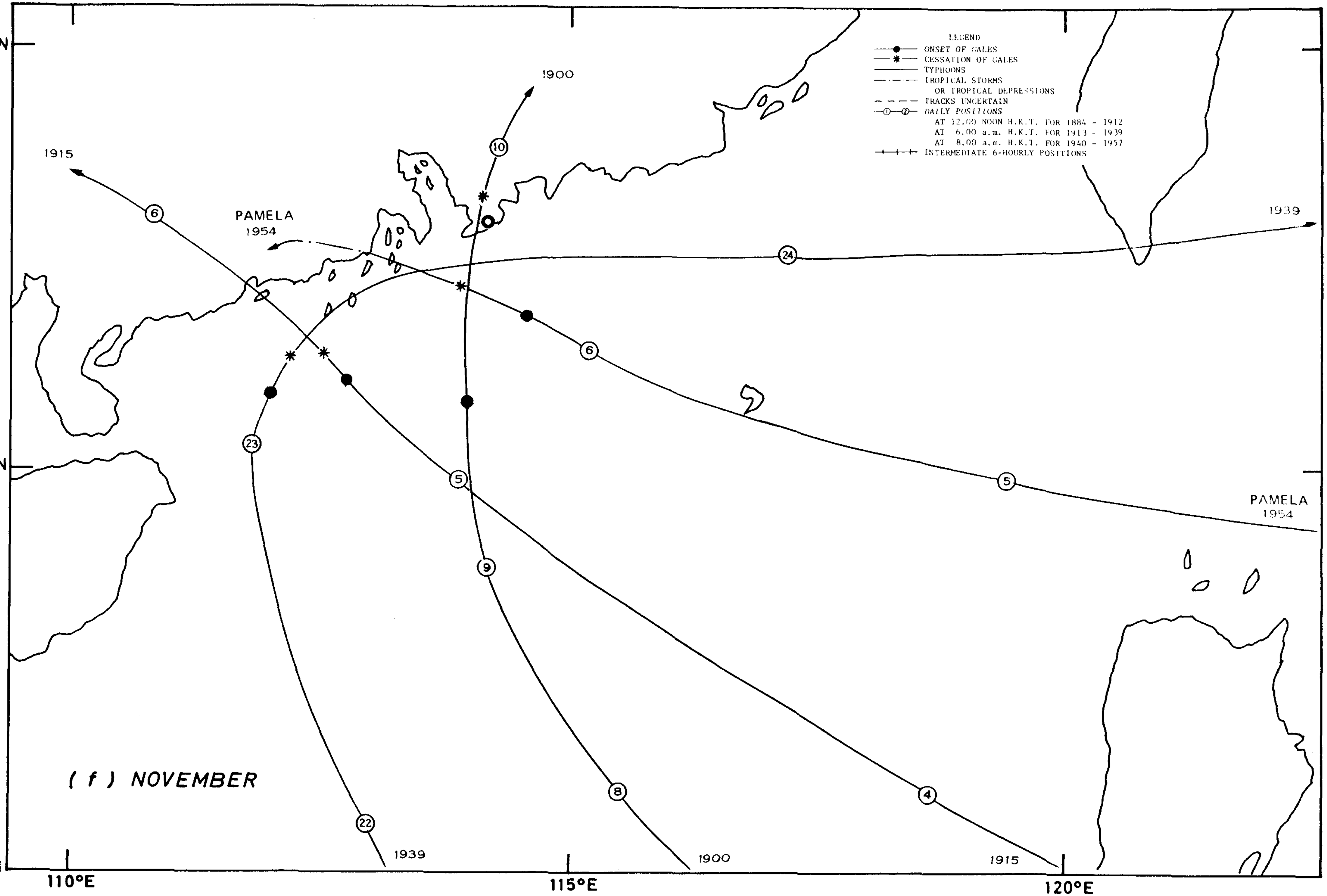


Figure 5. (Cont'd)

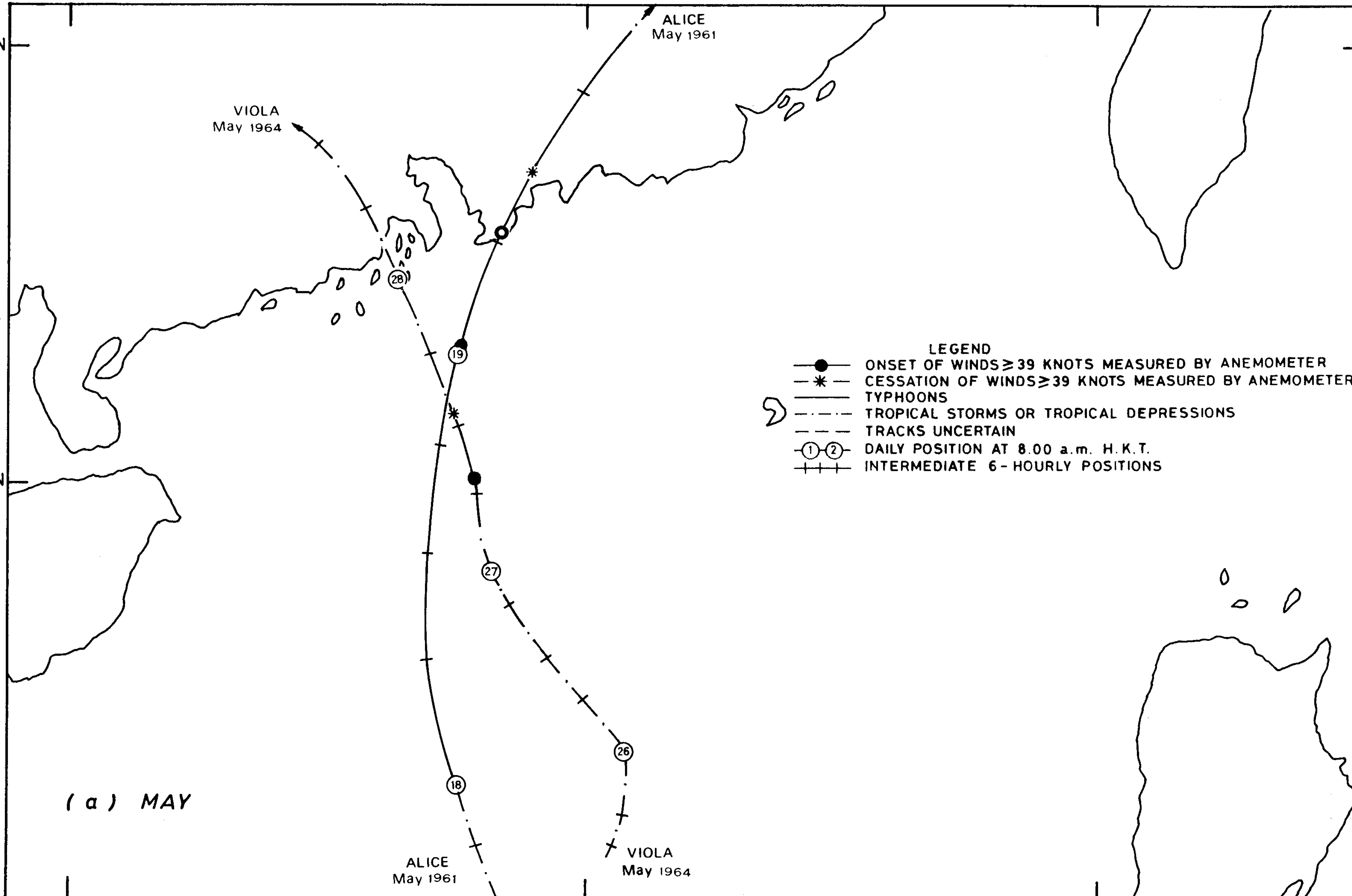
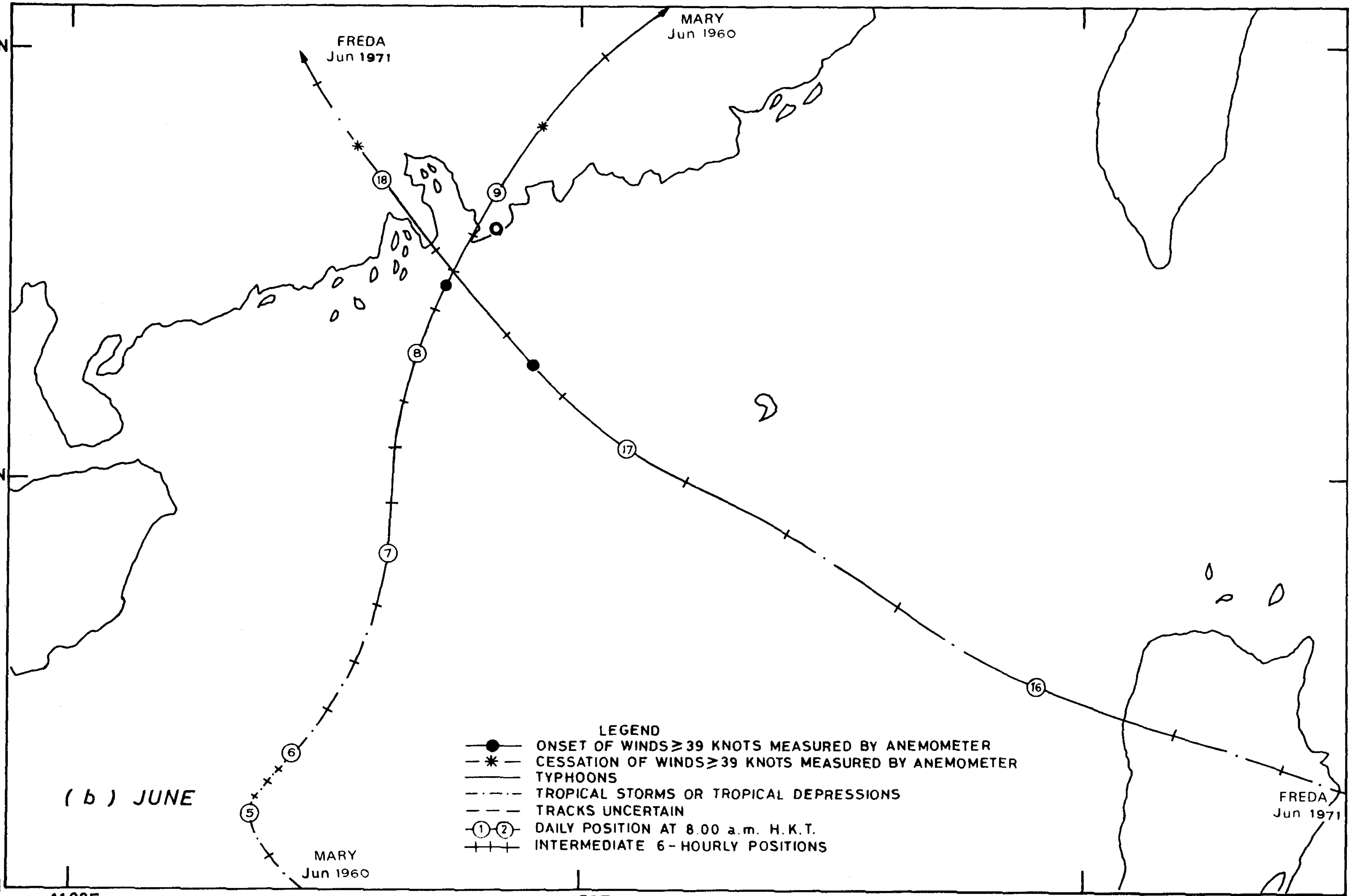


Figure 6. Tracks of tropical cyclones that caused persistent gales near sea level at Waglan Island 1953-1980.



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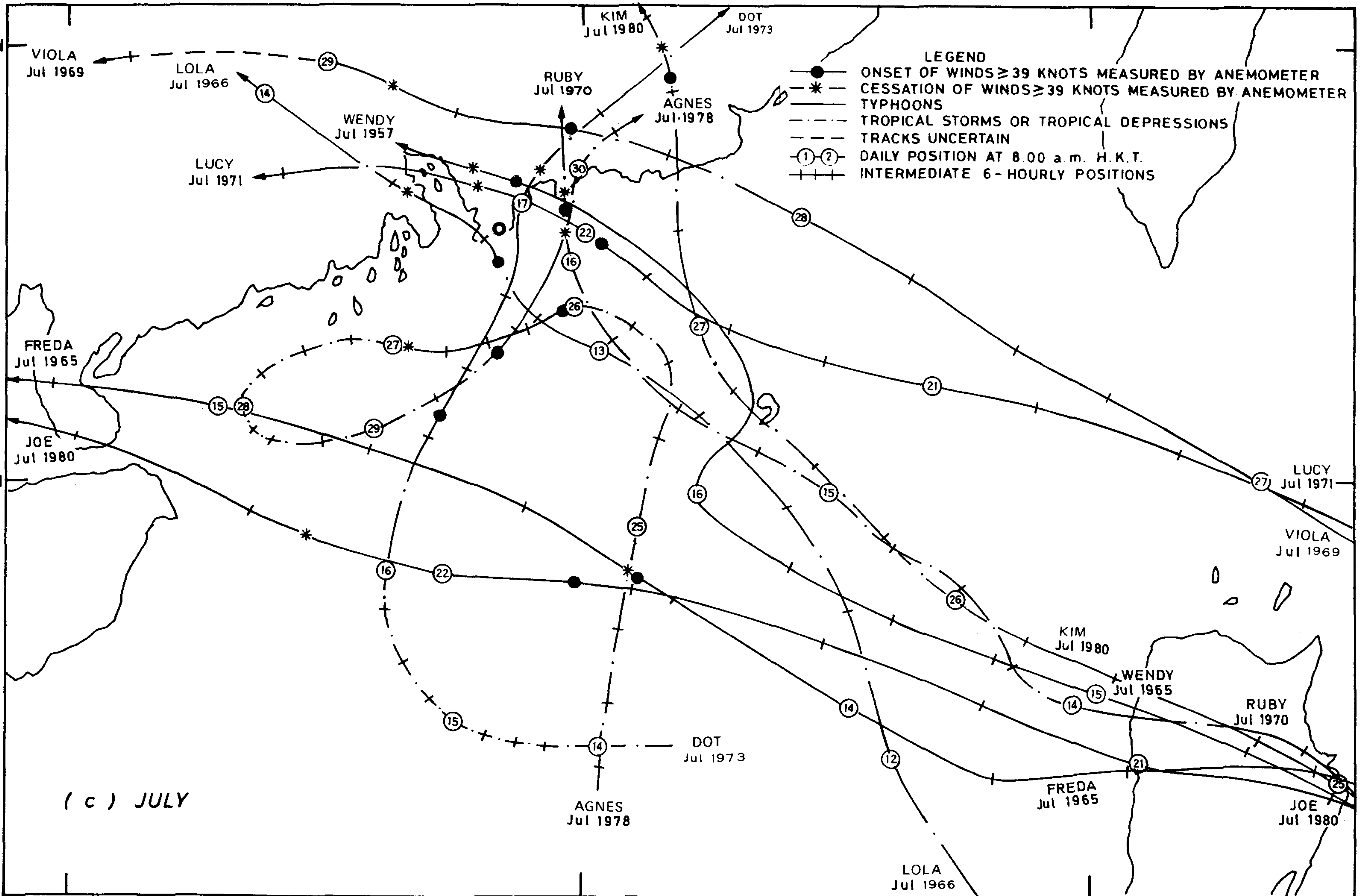

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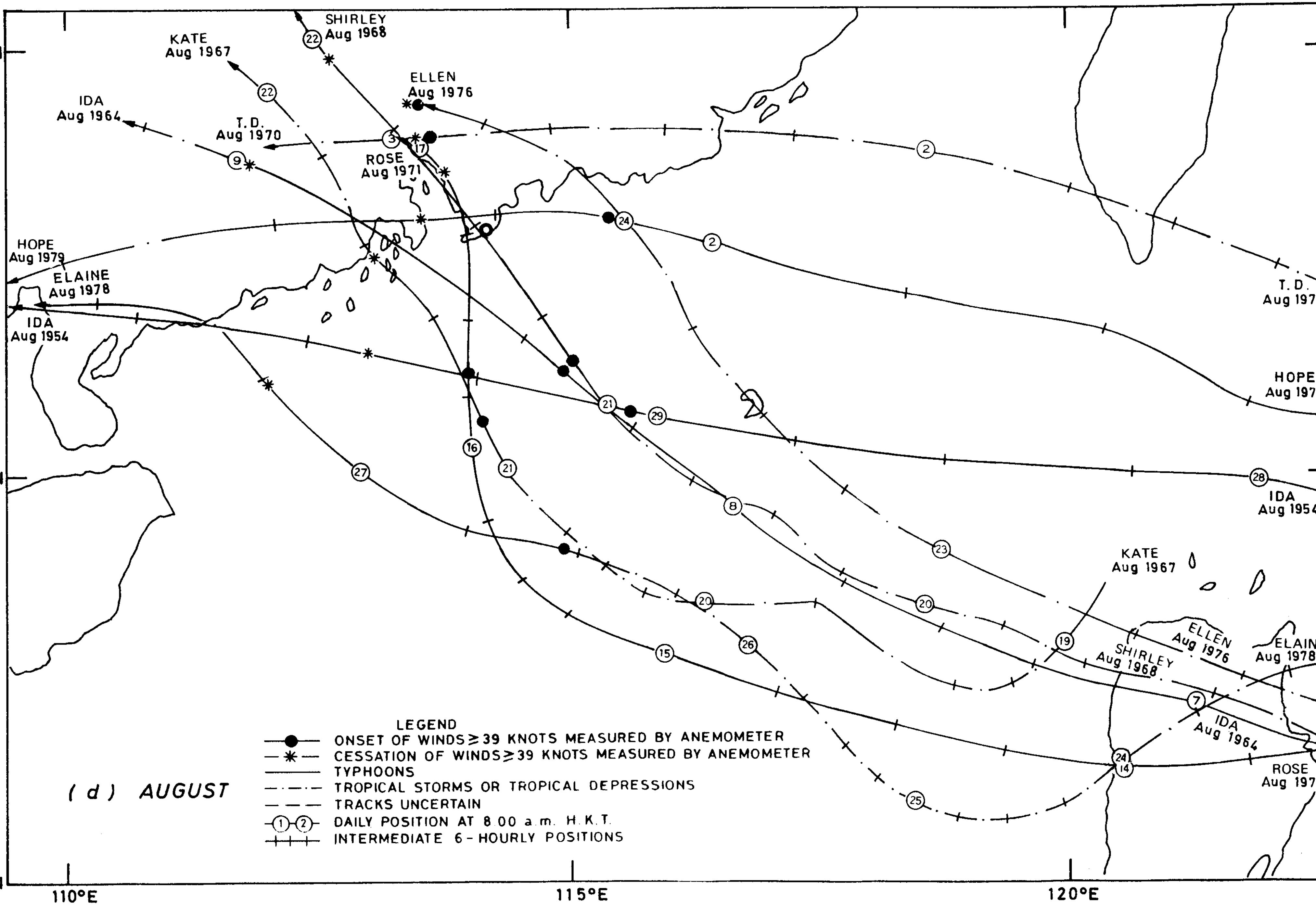

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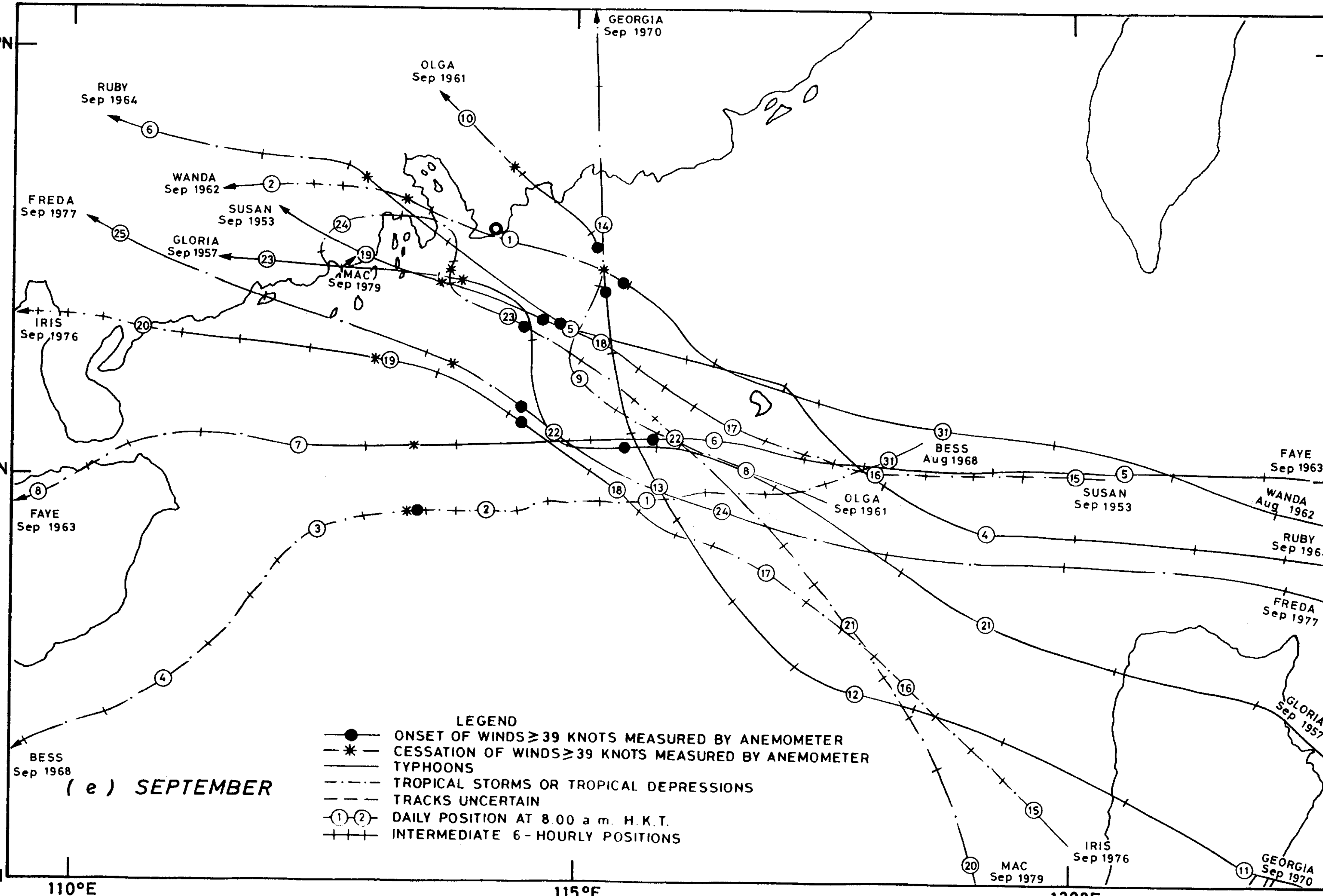

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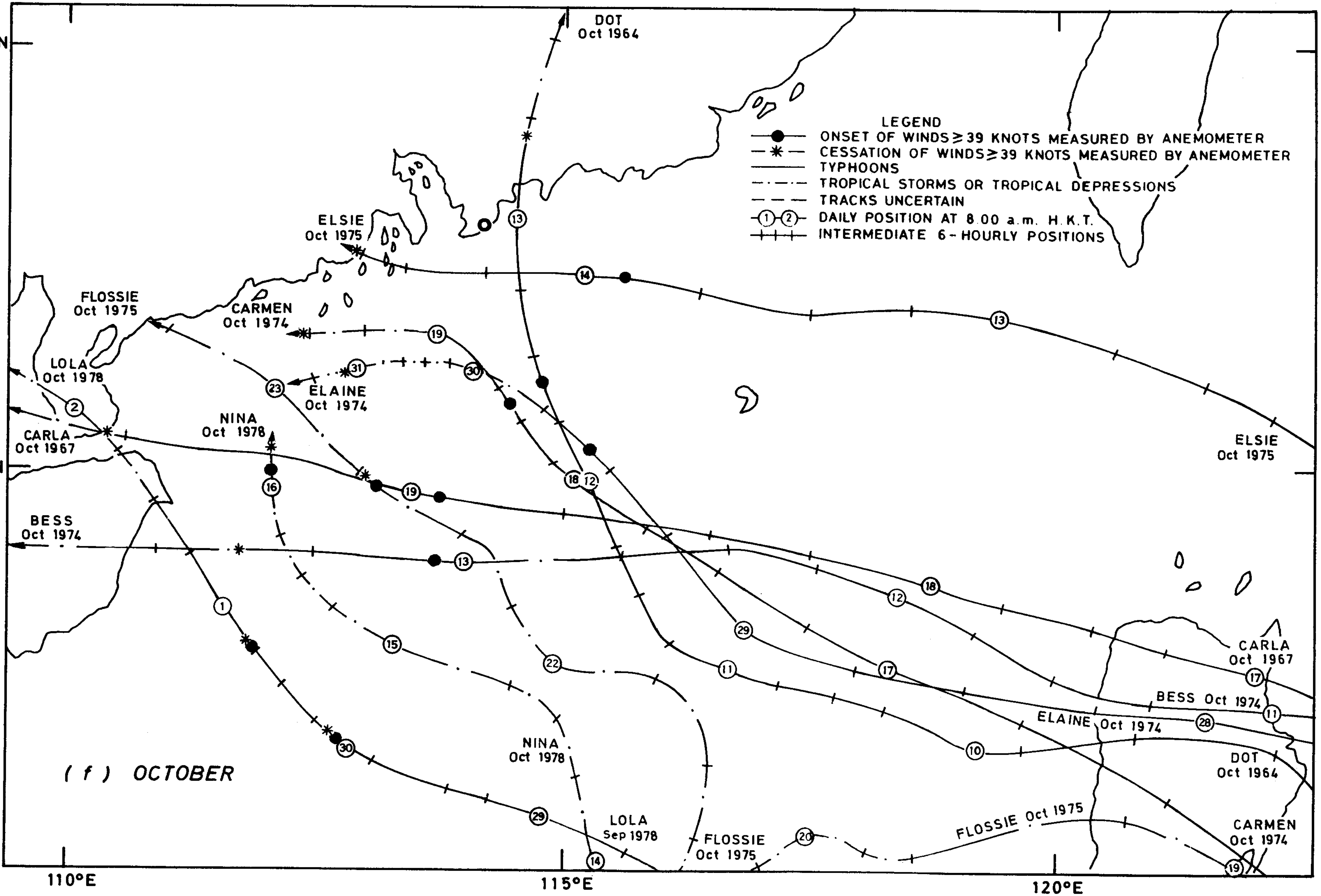

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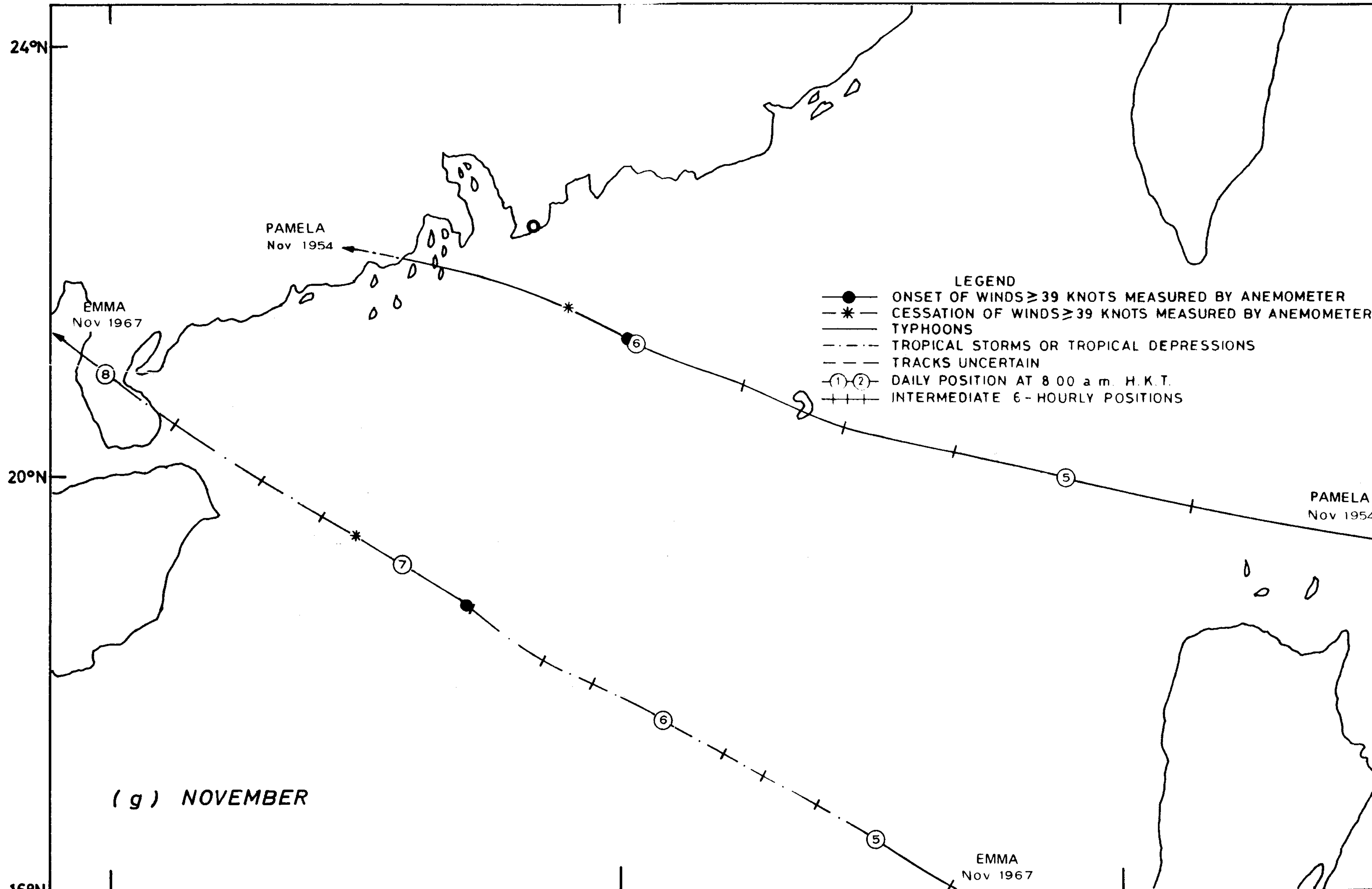

Figure 6· (Cont'd)