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TROPICAL CYCLONE RAINFALL IN HONG KONG

BY

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I. INTRODUCTION

In Hong Kong, tropical cyclones have caused much loss of human life and damage to property. Although the winds associated with a tropical cyclone are very strong and destructive, it is the rainfall that is often more disastrous. The heavy rain associated with a tropical cyclone very often causes landslides and flooding in low-lying areas. It was believed as early as in 1932 by Fr. Gherzi that during the heaviest typhoon squalls, the air might contain up to 50% of its volume of water. Such a mass of water, carried along with the wind, would enormously increase the destructive effect of the latter.

An example can be found in 1964 when Typhoon Sally passed about 30 nautical miles northeast of Hong Kong on September 9. The maximum gust recorded at the Royal Observatory was only 56 knots. However, the heavy rain associated with it caused many landslides and house collapses, claiming nine lives and injuring 24 people.

This technical note gives a statistical study of the rainfall amounts and variations recorded at the Royal Observatory due to the influence of all tropical cyclones passing within a range of 300 nautical miles from Hong Kong during the period 1884-1939 and 1947-1970. Dynamic or thermodynamic factors that govern the intensities of rainfall associated with tropical cyclones have not been considered in this paper.

II. TROPICAL CYCLONE WITHIN 300 NAUTICAL MILES OF HONG KONG

1. Normal Rainfall

Hong Kong is a hilly territory (location is given in Figure 1) and the area of land with an altitude less than 50 metres is only 15% of the total land area which is about 1050 square kilometers. Topographical effect plays an important part in the areal distribution of Hong Kong's rainfall. However, Starbuck (1950) found that Royal Observatory figures were representative of Hong Kong's areal rainfall to a very good approximation and this is confirmed by a recent analysis with the setting up of many rainfall stations in the east of Hong Kong. Therefore, unless otherwise stated, all rainfall data for Hong Kong mentioned in this paper refer to Observatory figures.

The 80-year mean annual rainfall for Hong Kong (Royal Observatory) during the period 1884-1939 and 1947-1970 is 2149.3mm. The features of Hong Kong rainfall pattern will not be elaborated here as they have already been described by many authors such as Starbuck (1950), Peacock (1952) and Peterson (1964). The mean monthly rainfall for the Royal Observatory is shown in Figure 2.

The mean monthly rainfall for two other stations, namely Waglan Island and Macau, are also given in Figure 2 for comparison. Waglan Island is about 10 nautical miles southeast of the Royal Observatory and is most exposed to the wind among these three stations. An exposed site is always a drawback to the accurate catch of the precipitation falling on the surrounding area. A sudden obstacle to the air trajectories tends to give rise to a deficiency in precipitation. The ideal exposure as recommended by the World Meteorological Organization is that the surrounding objects should be at a distance two to four times their height from the gauge.

The mean annual rainfall for Waglan Island is about 60% of that for the Royal Observatory. Macau is about 40 nautical miles west of Hong Kong, and its 80-year mean annual rainfall is about 80% of Hong Kong's mean.

2. Mean Tropical Cyclone Rainfall

Both Starbuck (1950) and Heywood (1950) found that tropical cyclones contributed about 20% to the annual total rainfall. Unfortunately, neither of them has defined the meaning of tropical cyclone rainfall. Tropical cyclone rainfall is defined arbitrarily here as the rainfall amount recorded at the Royal Observatory from the first civil day a tropical cyclone enters within 300 nautical miles of Hong Kong (Figure 3) until the last day it stays in this area, plus the rainfall amount recorded during the following 3 days. There may be a discrepancy of a few hours on the first day in determining the daily rainfall when a tropical cyclone has just moved in, but a few hours in several days is usually immaterial.

The annual tropical cyclone rainfall thus defined fluctuates tremendously from one year to another. It depends on many factors such as the number of tropical cyclones in the year, their intensities and directions of approach, and the efficiency of rain-producing mechanism of the tropical cyclones. The annual tropical cyclone rainfall varies from "nil" in 1901 to a maximum of 1235.7mm in 1964, contributing to the annual rainfall from 0% to 51%.

The 80-year mean annual tropical cyclone rainfall during 1884-1939 and 1947-1970 is 566.9mm which is about 26% of the mean annual rainfall for the Royal Observatory. The mean monthly tropical cyclone rainfall for the Royal Observatory is given in Figure 4.

The mean monthly rainfall due to tropical cyclones for Waglan Island and Macau are also given in Figure 4 for comparison. It is seen that tropical cyclones contributed more or less the same percentage of rainfall to the annual total at the three stations.

Tropical cyclone rainfall varies from one tropical cyclone to another. Mean rainfall at the Royal Observatory from one tropical cyclone is about 93.0mm whilst the extremes range from 597.4mm in July 1926 to "nil" on many occasions. Table 1 gives a comparison of the extreme values of tropical cyclone rainfall for the Royal Observatory, Macau and Waglan Island. The maximum values for Macau and Waglan Island are all lower than those for the Royal Observatory.

Table 1. Comparison of Extreme Values of Tropical Cyclone Rainfall (mm) for Royal Observatory, Macau and Waglan Island

	Royal Observatory	Macau	Waglan Island
Mean Annual Tropical Cyclone Rainfall	566.9	355.6	282.9
Maximum Annual Tropical Cyclone Rainfall	1235.7 (1964)	848.3 (1965)	567.3 (1965)
Minimum Annual Tropical Cyclone Rainfall	Nil (1901)	Nil (1901)	Nil (1901)
Mean Rainfall from a tropical cyclone	93.0	59.0	47.0
Maximum Rainfall from a tropical cyclone	597.4 (July 1926)	593.9 (Sept.1965)	385.3 (July 1959)
Minimum Rainfall from a tropical cyclone	Nil (many occasions)	Nil (many occasions)	Nil (many occasions)

3. "Direct" and "Indirect" Tropical Cyclone Rainfall

Some tropical cyclones brought very little rain to Hong Kong during their approaches, but enhanced the southwesterly flow which in turn caused heavy rainfall in Hong Kong after their passages. An example can be found in July 1926.

When the tropical cyclone was centred within 300 nautical miles of Hong Kong during the two days July 17-18, 1926, the total rainfall was only 34.8mm. The tropical cyclone then dissipated on the following day over south China about 150 nautical miles north of Hong Kong which was experiencing strong southwesterly flow. The rainfall on this day (July 19) amcunted to 534.1mm which was a result of the enhancement of the south-westerly monsoon. The rainfall intensity decreased when the winds backed to southeasterly and then easterly. During the following two days July 20-21, the rainfall was 28.5mm making a total of 597.4mm for the 3-day period after the passage of the tropical cyclone.

Let "direct" tropical cyclone rainfall be defined as the rainfall recorded during the period when the tropical cyclone is centred within 300 nautical miles of Hong Kong, and "indirect" tropical cyclone rainfall as the rainfall recorded during the following 3 days after the tropical cyclone has dissipated or moved outside 300 nautical miles of Hong Kong. It is found that the ratio of mean annual "indirect" tropical cyclone rainfall to mean annual "direct" tropical cyclone rainfall is about 2 to 3.

Comparison of the mean monthly "direct" and "indirect" tropical cyclone rainfall for Hong Kong is given in Table 2. It is noted that the "indirect" tropical cyclone rainfall is particularly high in July, about half of the total tropical cyclone rainfall for this month. During the dry months October through May, the "indirect" tropical cyclone rainfall in each month is negligible. This is expected since the winter monsoons from the north or northeast are dominant during this period (Bell and Chin, 1968).

Table 2. Comparison of Mean Monthly Tropical Cyclone Rainfall for Hong Kong (1884-1939, 1947-1970)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
"Direct" tropical cyclone rainfall	-	0.3	0.7	-	11.3	39.8	80.8	91.3	86.7	37.2	10.9	1.1	360.1
"Indirect" tropical cyclone rainfall	-	-	Tr	Tr	8.0	23.7	72.7	41.2	52.0	6.5	2.3	0.4	206.8
"Total" tropical cyclone rainfall	-	0.3	0.7	Tr	19.3	63.5	153.5	132.5	138.7	43.7	13.2	1.5	566.9

N.B. "Total" = "Direct" + "Indirect"

Table 2 compares the mean monthly "direct" and "indirect" tropical cyclone rainfall without taking into account the number of tropical cyclones which occurred in each month. The mean value for each month is obtained by averaging the total tropical cyclone rainfall over the number of years with records. As a result, the mean monthly tropical cyclone rainfall for June is only 63.5mm because the frequency of occurrence of tropical cyclones in this month is low. It may therefore be more preferable and practical to obtain the true mean values of the "direct", "indirect" and "total" tropical cyclone rainfall by taking into account the number of tropical cyclones occurring in each month. The result is given in Table 3.

Tropical cyclones which occurred during the summer months June to September produced more rain than those in the dry months. The range of the extremes in each month is very great, particularly in July, varying from "nil" to 600mm.

Table 3. Mean Rainfall from a tropical cyclone centred within 300 Nautical Miles of Hong Kong (mm) (1884-1939, 1947-1970)

Tropical Cyclone Rainfall		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
"Direct"	Mean	Nil	26.4	54.4	Nil	45.9	61.8	59.9	65.3	59.4	54.5	37.7	18.1	58.2
	Max.	Nil	26.4	54.4	Nil	276.6	494.7	320.8	443.2	397.5	427.1	149.2	39.1	
	Min.	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
"Indirect"	Mean	Nil	Nil	0.9	Trace	33.3	47.1	51.2	32.2	35.2	11.6	2.9	6.2	34.8
	Max.	Nil	Nil	0.9	Trace	353.0	258.6	562.6	306.1	237.7	111.3	121.5	21.4	
	Min.	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
"Total"	Mean	Nil	26.4	55.3	Trace	79.2	108.9	111.1	97.5	94.6	66.1	45.6	24.3	93.0
	Max.	Nil	26.4	55.3	Trace	353.0	559.8	597.4	447.5	527.4	427.4	154.7	60.5	
	Min.	Nil	Nil	Nil	Nil	Nil	0.4	Nil	Nil	Nil	Nil	Nil	0.8	

4. Frequency Distribution of Daily Rainfall Amounts

During the past 80 years, the frequency distribution of daily rainfall amounts due to tropical cyclones is similar to that due to all types of synoptic situation (including tropical cyclones). Appendix 1 shows the frequency distribution of daily rainfall amounts due to tropical cyclones within 300 nautical miles of Hong Kong (plus 3 additional days) during 1884-1939 and 1947-1970. For comparison, the frequency distribution of daily rainfall amounts due to all types of synoptic situation is reproduced in Appendix 2.

It can be seen from Appendices 1 and 2 that on average there would be 3 days per year with daily rainfall equal to or greater than 100 mm, and one of these 3 days would be caused by a tropical cyclone. If a day with daily rainfall ≥ 50mm is defined as a "wet day", the total number of wet days due to tropical cyclones is 286 against a total of 873 wet days during the past 80 years, a ratio of approximately 1 to 3. However, the frequency of occurrence of wet days due to tropical cyclones during the months July to October is significantly high, constituting 48.5% or nearly half of the total occurrences of wet days due to all types of synoptic situation during these months. The comparison of the occurrences of wet days in each month due to all types of synoptic situation with those due to tropical cyclones alone is given in Figure 5.

5. Extremes of Tropical Cyclone Rainfall

(a) Wettest Tropical Cyclones

Altogether there were 487 tropical cyclones that passed within 300 nautical miles of Hong Kong during the years 1884-1939 and 1947-1970. The frequency distribution of the 20 wettest tropical cyclones in terms of "direct", "indirect" and "total" tropical cyclone rainfall are listed in Table 4.

Table 4. Frequency Distribution of the 20 Wettest Tropical Cyclones within 300 Nautical Miles of Hong Kong (1884-1939, 1947-1970)

Type of Tropical Cyclone Rainfall	MAY	JUNE	JULY	AUG.	SEP.	OCT.	TOTAL
"Direct"	1	3	2	6	4	4	20
"Indirect"	1	4	9	4	2	0	20
"Total"	1	4	4	5	3	3	20

For both "direct" and "total" tropical cyclone rainfall, August records the greatest number of wettest tropical cyclones. It is interesting to note that nearly half of the 20 wettest tropical cyclones in terms of "indirect" rainfall are found to have occurred in July.

The 20 wettest tropical cyclones in terms of "total" "direct", and "indirect" rainfall are given in Appendices 3(a), 3(b) and 3(c) respectively, while the tracks of the top ten of each category are given in Appendices 4(a), 4(b) and 4(c) respectively.

Seven out of the ten wettest tropical cyclones in terms of "total" tropical cyclone rainfall passed within 100 nautical miles of Hong Kong. Two of the remaining three tropical cyclones which all landed more than 100 nautical miles to the east of Hong Kong occurred in July, their heavy rainfall being a result of the enhancement of the southwesterly flow.

Of the 10 wettest tropical cyclones in terms of "direct" rainfall, eight passed within 100 nautical miles of Hong Kong. It therefore appears that the "direct" tropical cyclone rainfall is greater if a tropical cyclone passes within 100 nautical miles of Hong Kong. It is seen that only two of the ten wettest tropical cyclones in terms of "indirect" rainfall passed within 100 nautical miles of Hong Kong. The top five all landed to the east of Hong Kong, four of them being outside 100 nautical miles.

(b) Driest Tropical Cyclones

There were 21 tropical cyclones which gave nil or just a trace of rainfall when they were centred within 300 nautical miles of Hong Kong (Listed in Appendix 5). All the tropical cyclones in this list passed outside 100 nautical miles of Hong Kong. This indicates that if a tropical cyclone passes within 100 nautical miles of Hong Kong, it is likely to cause some rain in Hong Kong even though it might be a "dry" one. Tracks of the 17 driest tropical cyclones without any measurable rainfall are given in Appendix 6. It might be worth noting that practically all of them landed to the east of Hong Kong. However, a tropical cyclone that lands to the east of Hong Kong can be very wet or very dry, depending on other factors.

6. Relationship Between Overall Rainfall and Tropical Cyclone Rainfall

An attempt was made to correlate the overall rainfall due to all types of synoptic situation (including tropical cyclones) with the tropical cyclone rainfall to see whether they are negatively or positively correlated.

The first attempt was made with the annual overall rainfall and the annual tropical cyclone rainfall. Table 5(a) is a contingency table showing the number of dry or wet years associated with below or above normal tropical cyclone rainfall. A dry or wet year is here defined according to whether the annual rainfall is below or above the mean annual total of 2149.3 mm. Mean annual tropical cyclone rainfall is 566.9mm as given in Table 1.

Subsequent attempts were done for the months June to September. Tables 5(b) to 5(c) are contingency tables for the months June to September relating the frequency of monthly tropical cyclone rainfall to that of monthly rainfall due to all types of synoptic situation.

Table 5(a) Contingency Table of Annual Rainfall

(1884-1939, 1947-1970)

Annual Rainfall Due to All Types of Synoptic Situation # / Annual Tropical Cyclone Rainfall	Dry Year	Wet Year	Total
No. of Years below normal	24	16	40
No. of Years above normal	15	25	40
Total	39	41	80

\# including tropical cyclones

Table 5(b) Contingency Table of Monthly Rainfall for June

Mean Rainfall for JUN = 403.6 mm / Mean Monthly Tropical Cyclone Rainfall = 63.5	Below	Above	Total
Below	38	20	58
Above	7	15	22
Total	45	35	80

Table 5(c) Contingency Table of Monthly Rainfall for July

Mean Rainfall for JULY = 361.6 mm / Mean Monthly Tropical Cyclone Rainfall = 153.5 mm	Below	Above	Total
Below	39	10	49
Above	9	22	31
Total	48	32	80

Table 5(d) Contingency Table of Monthly Rainfall for August

Mean Rainfall for AUG = 368.8 mm / Mean Monthly Tropical Cyclone Rainfall = 132.5 mm	Below	Above	Total
Below	36	16	52
Above	9	19	28
Total	45	35	80

Table 5 (e) Contingency Table of Monthly Rainfall for September

Mean Rainfall for SEP = 284.3 mm / Mean Monthly Tropical Cyclone Rainfall = 138.7 mm	Below	Above	Total
Below	41	10	51
Above	5	24	29
Total	46	34	80

Chi square test have been done for these tables, and the following results are obtained :

(a) ANNUAL	Probably significant (*)
(b) JUNE	Probably significant (*)
(c) JULY	Highly significant (***)
(d) AUGUST	Highly significant (***)
(e) SEPTEMBER	Highly significant (***)

The terms and symbols used to denote the significance levels of the tests are adopted from the convention used by Peacock (1972). Below is a reproduction of this system which will be used throughout this paper in testing the relationship between two sets of variables.

Not significant	(N.S.)	- Not statistically significant at the 0.05 level
Probably significant	(*)	- Significant at the 0.05 level, but not at the 0.01 level.
Significant	(**)	- Significant at the 0.01 level, but not at the 0.001 level.
Highly significant	(***)	- Significant at the 0.001 level.

The above results show that the contribution of tropical cyclone rainfall to the overall monthly rainfall is very important during the months July to September. However, it should be borne in mind that there are more dry than wet months, and more months with below-average tropical cyclone rainfall than above.

Attempts have also been made to correlate the tropical cyclone rainfall with rainfall due to other causes (total rainfall less tropical cyclone rainfall) for each month from May to November. The correlation coefficients are given in Table 6.

Table 6. Relationship Between Tropical Cyclone Rainfall and Rainfall Due to Other Causes (1884-1939, 1947-1970)

Month/ Period	No. of Observations	Correlation Coefficient	Significance for Specific Number of Observations
MAY	19	- 0.05	Not significant (N.S.)
JUN	45	- 0.29	Not significant (N.S.)
JUL	66	- 0.34	Significant (**)
AUG	62	- 0.20	Not significant (N.S.)
SEP	59	- 0.01	Not significant (N.S.)
OCT	41	0.01	Not significant (N.S.)
NOV	23	0.25	Not significant (N.S.)
JUN-SEP	79	- 0.36	Significant (**)
YEAR	79	- 0.28	Probably significant (*)

The correlation coefficients are significant only for the month of July and for the 4-month period June to September. It is, however, interesting to note that the coefficients for the months of October and November change sign from negative to positive. This suggests that the rainfall variations in these two months depend very much upon the frequency of occurrence of tropical cyclones.

II. TROPICAL CYCLONES WITHIN 100 NAUTICAL MILES OF HONG KONG

1. Classification

It is shown that the precipitation in a tropical cyclone is concentrated in the inner core where the pressure profile has its steepest slope (Riehl, 1954). Rainfall therefore intensifies as the centre approaches close to Hong Kong.

It has already been pointed out that the greatest tropical cyclone rainfall occurs where the tropical cyclones pass within 100 nautical miles of Hong Kong. When a tropical cyclone is centred at such a close distance, gales are experienced at Hong Kong on most occasions(Royal Observatory Meteorological Results, 1884-1970). The destructive effect of the tropical cyclone on human lives and property also becomes more severe. A more detailed study of all the tropical cyclones passing within 100 nautical miles of Hong Kong is therefore necessary.

2. Frequency Distribution of Tropical Cyclones

On average, at least 20 tropical cyclones develop each year in the western North Pacific and the China Seas (Chin, 1972). Of these tropical cyclones only a small proportion pass within 300 nautical miles of Hong Kong and a smaller proportion pass sufficiently close to Hong Kong to cause gales locally.

The number of occurrences of tropical cyclones that pass within 300 nautical miles of Hong Kong fluctuates greatly from year to year, varying from nil in 1901 to a maximum of 12 in 1947. The mean of the extremes is 6 which is also the mean of the total occurrences. In other words, only 1/3 of the tropical cyclones which develop over the Pacific Ocean and the South China Sea would pass within 300 nautical miles of Hong Kong.

Again, only one third of these tropical cyclones would move within 100 nautical miles of Hong Kong. A tropical cyclone would pass directly over Hong Kong (within 15 nautical miles of the Royal Observatory) only once in every 4 years. Table 7 lists the total number of occurrences of tropical cyclones at different ranges of distance from Hong Kong for each month.

No tropical cyclones have ever come within the 300 nautical mile radius area in January, and only one in every 4 years does so in May. Tropical cyclones are more frequent during the months July to September, with a peak in August. The probability that a tropical cyclone would pass within 100 nautical miles of Hong Kong is also greatest in August, about once in every two years.

As to be expected, not one tropical cyclone has ever come within 100 nautical miles of Hong Kong during the months December through April. In November, however, there is still a possibility that a tropical cyclone might pass close to Hong Kong. From past records, two tropical cyclones virtually crossed directly over Hong Kong in November. In 1900 a typhoon landed less than 10 nautical miles west of the Royal Observatory on November 10, and in 1939 a typhoon recurved to move eastward and passed about 15 nautical miles south of the Royal Observatory on November 23.

Table 7 Occurrences of Tropical Cyclones at Different Ranges of Distance from Hong Kong

(1884-1939, 1947-1970)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Mean No. of Trop. Cyclone per year
Total No. of tropical cyclones within 300 nautical miles of Hong Kong	0	1	1	2	22	54	106	113	108	52	23	5	487	6
Total No. of tropical cyclones within 100 nautical miles of Hong Kong	0	0	0	0	6	16	29	38	33	11	7	0	140	2
Total No. of tropical cyclones crossing Hong Kong	0	0	0	0	1	1	6	6	5	0	2	0	21	1/4
Frequency of occurrence of tropical cyclones within 300 nautical miles of Hong Kong	-	$\frac{1}{80}$	$\frac{1}{80}$	$\frac{1}{40}$	1/4	$\frac{2}{3}$	1 1/4	$1\frac{1}{3}$	1 1/4	$\frac{2}{3}$	1/4	$\frac{1}{20}$	6	6
Frequency of Occurrence of tropical cyclones within 100 nautical miles of Hong Kong	0	0	0	0	$\frac{1}{10}$	$\frac{1}{5}$	$\frac{1}{3}$	1/2	$\frac{2}{5}$	1/5	$\frac{1}{10}$	0	2	2

3. Rainfall Variations

(a) Monthly Rainfall Variations

A tropical cyclone that passes within 100 nautical miles of Hong Kong will, generally speaking, bring more rain to Hong Kong than one passing outside this range. In this paper the rainfall brought by a tropical cyclone within 100 nautical miles of Hong Kong is reckoned from the first civil day it moves into the 300 nautical miles range from Hong Kong until 3 days after it has dissipated or moved away.

The monthly variations of mean rainfall brought by a tropical cyclone at different ranges of distance from Hong Kong are given in Figure 6. The mean rainfall brought by a tropical cyclone passing within 100 nautical miles of Hong Kong is about 150 mm, twice as much as one passing outside 100 nautical miles but within 300 nautical miles of Hong Kong. A tropical cyclone that crosses directly over Hong Kong (within 15 nautical miles) produces less rain than one passing outside 15 nautical miles but within 100 nautical miles of Hong Kong.

The monthly variations of mean rainfall produced by tropical cyclones passing within the annular sector of 300 to 100 nautical miles from Hong Kong are very marked. The mean tropical cyclone rainfall rises from May until July, and then decreases gradually with each month. The rainfall amount for May is just half of that for July, but nearly twice as much as that for October.

However, the mean rainfall brought by tropical cyclones passing within 100 nautical miles of Hong Kong does not vary very much with each month. The mean rainfall for the months of May July, August and September are practically the same. Surprisingly the mean rainfall for October is exceptionally high. In this month, the rainfall brought by a tropical cyclone passing within 100 nautical miles of Hong Kong is nearly six times as much as that due to one passing within 300 to 100 nautical miles of Hong Kong.

(b) Rainfall Variation with Tracks of Tropical Cyclones

The rainfall produced by a tropical cyclone depends very much upon its direction of approach to Hong Kong. It is a function of the moisture charge in the lower troposphere and the efficiency of the storm mechanism (Bell & Chin, 1968). In order to study the rainfall variations with tracks of tropical cyclones more in detail, all tropical cyclones passing within 100 nautical miles of Hong Kong are classified into 5 types, viz. :

(i) Type "T_o" .... Tropical cyclones crossing Hong Kong, within 15 nautical miles, irrespective of any direction of approach, and accompanied with sharp changes in wind direction.

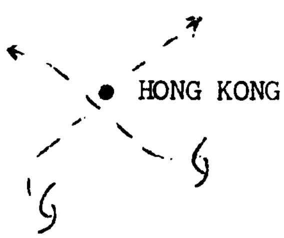
(ii) Type "T_{RE}"........ Tropical cyclones which recurve to land to the east of Hong Kong.

(iii) Type "T_{RW}"........ Tropical cyclones which recurve to land to the west of Hong Kong.

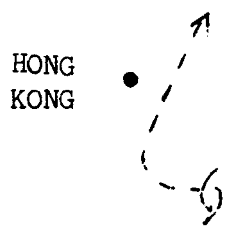
(iv) Type "T_{PE}"........ Tropical cyclones moving on a fairly steady direction, which land to the east of Hong Kong.

(v) Type "T_{PW}" .... Tropical cyclones moving on a fairly steady direction, which land to the west of Hong Kong.

Type "T_o"

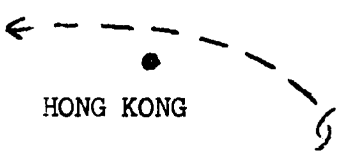


Type "T_{RE}"

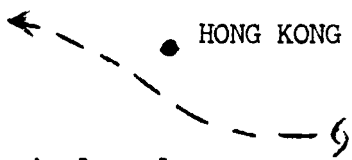


Type "T_{RW}"

Type "T_{PE}"



Type "T_{PW}"



N.B.  denotes the centre of a tropical cyclone.

Comparison of rainfall brought by tropical cyclones on the above 5 tracks within 100 nautical miles of Hong Kong is given in Table 8. It is observed that the mean rainfall of those tropical cyclones approaching on track T_{RW} is greater than that of those on other tracks, i.e., tropical cyclones which are centred to the southwest of Hong Kong and recurve to land west of Hong Kong are more rain bearing than all other types of tropical cyclones.

Table 8. Comparison of Rainfall Due To Tropical Cyclones On Different Tracks Within 100 Nautical Miles Of Hong Kong (1884-1939, 1947-1970)

Track of Tropical Cyclone	Total No. of Occurrences	"Direct" Tropical Cyclone Rainfall			"Indirect" Tropical Cyclone Rainfall			"Total" Tropical Cyclone Rainfall		
		Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.
T_o	21	419.9 (Jun 1960)	121.8	4.6 (Sep 1933)	79.3 (Sep 1931)	19.1	Nil (1900, 1908, 1971)	422.7 (Jun 1960)	140.9	39.5 (Jul 1911)
T_{RE}	21	494.7 (Jun 1916)	101.9	Nil (May 1906)	108.7 (Aug 1904)	29.4	Nil (1893, 1938, 1947)	559.8 (Jun 1916)	131.3	5.6 (Jun 1905)
T_{RW}	12	427.1 (Oct 1894)	153.3	16.9 (Sep 1895)	168.4 (Sep 1952)	37.6	0.3 (October 1894)	427.4 (Oct 1894)	190.9	18.0 (Sep 1895)
T_{PE}	31	310.9 (Aug 1902)	103.2	3.8 (Jun 1952)	306.1 (Aug 1923)	54.5	Nil (1931, 1937)	405.7 (Aug 1923)	157.7	23.6 (Nov 1931)
T_{PW}	55	320.6 (Oct 1909)	112.9	5.1 (Aug 1895)	232.5 (Jun 1910)	32.2	Nil (1898)	437.9 (Aug 1911)	145.2	8.9 (Aug 1895)
Overall	140	494.7 (Jun 1916)	113.9	Nil (May 1906)	306.1 (Aug 1923)	35.3	Nil (many occasions)	559.8 (Jun 1916)	149.2	5.6 (Jun 1965)

One interesting point is that the "indirect" rainfall recorded during the 3-day period after the passage of a tropical cyclone is, in all cases, much lower than the "direct" rainfall recorded during the period when it is centred within 300 nautical miles of Hong Kong. The ratio of "indirect" to "direct" rainfall for all tropical cyclones within 300 nautical miles of Hong Kong as shown in Table 3 is about 2 to 3, whereas such ratio for all tropical cyclones within 100 nautical miles is only 1 to 3.

The "indirect" rainfall from tropical cyclones passing directly over Hong Kong is particularly low. The mean "indirect" rainfall from such tropical cyclones is about 20 mm only, and the corresponding "direct" rainfall is about 120 mm. Among the 21 tropical cyclones on such a track, the maximum "indirect" rainfall is 79.3 mm which was recorded on September 4-5, 1931, and there was no rainfall on the 6th.

Rainfall during the 3-day period after the passage of a tropical cyclone crossing Hong Kong might therefore be reckoned as negligible. Comparison of the mean daily "indirect" rainfall for tropical cyclones on different tracks is given in Table 9.

Table 9. Mean Daily "Indirect" Rainfall For Tropical Cyclones on Different Tracks Within 100 Nautical Miles of Hong Kong (1884-1939, 1947-1970)

Track / Day after passage of tropical cyclone	T_O	T_{RE}	T_{RW}	T_{PE}	T_{PW}	Overall
1st	13.8	12.0	14.7	33.3	22.4	21.3
2nd	4.3	9.4	13.4	11.9	5.6	8.1
3rd	1.0	8.0	9.5	9.3	4.2	5.9
TOTAL	19.1	29.4	37.6	54.7	32.2	35.3

Heywood (1950) found that rainfall was greater and more prolonged after the passage of a tropical cyclone than before. However, this is true only for those tropical cyclones moving fairly steadily from the east. For recurving tropical cyclones, i.e. those on track T_{RE} or T_{RW}, the rainfall before the passage is much higher than after. The mean 30-hour rainfall before the passage of a tropical cyclone on track T_{RE} or T_{RW} is about 50% more than that recorded after its passage.

Table 10 compares the mean 30-hour rainfall recorded before and after the passage of a tropical cyclone on each track within 100 nautical miles of Hong Kong. The mean 30-hour rainfall after the passage of a tropical cyclone on either track T_{PE} or T_{PW} is significantly higher than that recorded before its passage. This is as expected because strong northerly winds (which are relatively dry) are usually experienced in Hong Kong as the centre of the tropical cyclone on either track approaches.

Table 10. Mean 30-hour Rainfall Before & After the Passage of a Tropical Cyclone on Different Track Within 100 Nautical Miles of Hong Kong (1884-1939, 1947-1970)

Track \ Rainfall (mm)	Before Passage (A)	After Passage (B)	60-Hour Total (A+B)	Ratio : $\frac{A}{B}$
T_o	59.9	77.4	137.3	0.75
T_{RE}	62.6	38.8	101.4	1.50
T_{RW}	91.1	64.2	155.3	1.50
T_{PE}	32.7	86.9	119.6	0.33
T_{PW}	41.5	83.0	124.5	0.50
Overall	49.8	74.8	124.6	0.67

4. Rainfall Profiles

(a) Mean Hourly Rainfall Profile

The results given in Table 10 are depicted in profiles of mean hourly rainfall shown in Figure 7 for tropical cyclones on specific tracks within 100 nautical miles of Hong Kong. The rainfall of the 3 intense typhoons affecting Hong Kong in 1971, viz, Freda, Lucy and Rose, have also been incorporated into the mean values. The period covered by each profile starts from 30 hours before the nearest approach of a tropical cyclone to Hong Kong until 30 hours after its passage. The hour of lowest hourly mean sea level pressure at the Royal Observatory is used to represent the hour of the nearest approach.

For a tropical cyclone passing directly over Hong Kong, most of the rainfall is recorded during a period of 6 hours on both sides of its nearest approach to Hong Kong. The rainfall is slightly more intense and prolonged after the passage and dips slightly at the hour of the nearest approach.

In general, the mean rainfall becomes more intense as a tropical cyclone is approaching, and there are no sharp rises or drops in mean intensity for each type of tropical cyclone passing within 100 nautical miles of Hong Kong. However, deviations from the mean are very great for individual tropical cyclones.

(b) Mean Accumulated Rainfall Profile

Figure 8 shows the mean accumulated rainfall profile for tropical cyclones on each track within 100 nautical miles of Hong Kong in 6-hourly intervals. The form of the curves varies little, the wetter the tropical cyclone the steeper the curve. All curves show a gradual flattening out 12 hours after the nearest approach of a tropical cyclone.

5. Rainfall Intensities With Distance From Typhoon Centre

Rainfall intensity normally decreases with distance from the centre of a tropical cyclone. Riehl (1954) found

that $$P = \frac{2V_r}{r} \bar{q} \frac{\Delta P}{g}$$

where P = rainfall per unit area and time

$V_r \frac{\Delta P}{g}$ = mass flux across circulation circle

$\bar{q}$ = specific humidity of the inflow

r = radius of circulation

His calculation of rainfall intensities with distance from the centre of a typhoon is reproduced in Figure 9. A similar attempt has been made to correlate the 24-hour rainfall amount at the Royal Observatory with distance from typhoon centre. Only tropical cyclones of typhoon intensity are incorporated in the calculation.

The regression line thus obtained is given also in Figure 9 to compare with Riehl's. His result shows a steeper slope than that of Observatory figures. Near the centre of a typhoon, both results are comparable. The higher rainfall intensities in the Royal Observatory's curve at greater ranges of distance are probably due to oreigenic effects. For instance, when a typhoon is about 300 nautical miles away, Hong Kong may still be outside the typhoon's circulation. However, the northerly flow, though usually dry, occasionally gives rise to thunderstorms in Hong Kong, especially during the first onset of the flow. A good example although not due to a typhoon can be found in 1965 when Tropical Storm Harriet was 280 nautical miles east-northeast of Hong Kong on July 27. Thunderstorms and heavy rain were reported at the Royal Observatory and at all outstations.

Similar calculation of typhoon rainfall intensities for Waglan Island with distance from typhoon centre has also been attempted and the result is given again in Figure 9 for comparison. Waglan's rainfall shows a similar slope to that for the Royal Observatory. It is, however, curious that the rainfall rate at close approaches is so low at Waglan Island.

The only explanation of the 3 different slopes of rainfall rate as shown in this diagram may be due to the fact that raingauge measurements give only a poor approximation of tropical cyclone rainfall as mentioned by Riehl (1954). Over-exposure as in the case of Waglan Island causes the rain to be swept along almost horizontally, thus resulting in an apparent reduction in precipitation. The deficiency naturally becomes greater when winds of gale force or above are experienced at the site during the approach of a typhoon.

6. Relationship Between Rainfall And Minimum Pressure

An attempt was made to correlate the rainfall amount with the minimum hourly mean sea level pressure at the Royal Observatory for tropical cyclones passing on different tracks within 100 nautical miles of Hong Kong. The three intense typhoons in 1971 have also been included in the calculation.

The results of such correlation are given in Table 11. Three categories of rainfall amounts were used. The correlation is quite significant in most cases. The correlation coefficients **are particularly high for 'overall' tropical cyclones passing** within 100 nautical miles of Hong Kong (without discrimination of tracks). They all exceed the value of significance at 0.001 level. Such results should be useful in preparing rainfall forecasts because pressure is a continuous parameter that can be predicted with greater confidence.

The regression lines for each category of rainfall relating with the minimum pressure (at Royal Observatory) of each type of tropical cyclones within 100 nautical miles of Hong Kong are given in Figure 10(a), 10(b) and 10(c).

Table 11. Relationship Between Tropical Cyclone Rainfall And Minimum Hourly Mean Sea Level Pressure At the Royal Observatory

Track of tropical cyclones within 100 nautical miles of Hong Kong	No. of Cases, N	(i) 24-Hour Rainfall		(ii) 3-Day Rainfall		(iii) Total Rainfall	
		Correlation Coefficient	Significance for specific "N"	Correlation Coefficient	Significance for specific "N"	Correlation Coefficient	Significance for specific "N"
T_o	22	-0.39	N.S.	-0.34	N.S.	0.32	N.S.
T_{RE}	21	-0.55	**	-0.53	*	-0.43	*
T_{RW}	12	-0.85	***	-0.74	**	-0.65	*
T_{PE}	32	-0.42	*	-0.32	N.S.	-0.46	**
T_{PW}	56	-0.53	***	-0.42	**	-0.44	***
Overall	143	-0.49	***	-0.37	***	-0.37	***

N.B. (i) "24-hour rainfall" is the amount recorded during the 24-hour period centred on the hour of minimum mean sea level pressure at Royal Observatory.

(ii) "3-day rainfall" is the amount recorded during the 3-day period centred on the hour of minimum mean sea level pressure at Royal Observatory.

(iii) "Total rainfall" is the amount recorded during the period when a tropical cyclone is centred within 300 nautical miles of Hong Kong until 3 days after its dissipation or moving away.

IV. RECURRENCE INTERVALS OF VARIOUS RAINFALL AMOUNTS

1. Annual Extreme Maximum Daily Rainfall

Very heavy rainfall in Hong Kong may be quite unconnected with a tropical cyclone. It is worthwhile to compare the annual extremes of tropical cyclone rainfall with rainfall due to other causes for different periods.

The determination of the return period of extreme values was based on Gumbel's method (1960). There are one or two years in which no tropical cyclones passed within 300 nautical miles of Hong Kong, and the average number of such tropical cyclones is only 6 per year. All data were then tabulated into groups of 3 consecutive years. In this way, the population is just big enough to give a significant extreme value.

The Gumbel lines for the 3-year extreme values of daily tropical cyclone rainfall and non-tropical cyclone rainfall (due to other causes) are given in Figures 11(a) and 11(b). The regression line of extreme daily tropical cyclone rainfall is reproduced in Figure 11(b) for comparison. It is seen that the non-tropical cyclone rainfall has a similar slope to that of tropical cyclone rainfall.

The annual extreme maximum daily tropical cyclone rainfall and non-tropical cyclone rainfall are listed in Appendices 7(a) and 7(b).

2. Annual Extreme Maximum Hourly Rainfall

The annual extreme maximum hourly rainfall due to tropical cyclones and other synoptic situations are listed in Appendices 8(a) and 8(b).

Gumbel curves for the 3-year extreme values of hourly tropical cyclone rainfall and non-tropical cyclone rainfall are given in Figures 12(a) and 12(b). Unlike the curves for daily rainfall amounts, the slope of the regression line for hourly non-tropical cyclone rainfall is steeper than that for hourly tropical cyclone rainfall. This tends to suggest that the rainfall intensity with a thunderstorm is greater than that with a tropical cyclone.

3. Annual Extreme Maximum Instantaneous Rate of Rainfall

Records of instantaneous rates of rainfall from Jardi gauge are available only after 1952 from King's Park Meteorological Station, about 1 kilometer north of Royal Observatory. Gumbel lines of extreme instantaneous rates of tropical cyclone and non-tropical cyclone rainfall are given in Figures 13(a) and 13(b).

It is interesting to note that the extreme maximum instantaneous rate of tropical cyclone rainfall is practically comparable to that of trough-type or thunderstorm rainfall. The maximum instantaneous rate of tropical cyclone rainfall is 301 mm/h recorded at 1946 hours G.M.T. on October 12, 1964, while that of non-tropical cyclone rainfall is 320 mm/h at 0058 hours G.M.T. on August 3, 1955. However, a new record of maximum rate of tropical cyclone rainfall was observed in 1971 at Tate's Cairn during the passage of Typhoon Rose around 0300 hours G.M.T. on August 17. The pen rose above the upper limit of the chart but the rate was estimated to be 513 mm/h.

It is found that rain cells in a tropical cyclone move faster than those due to local convection or large scale surface convergence (Bell, 1970). Besides, raingauge measurements under high wind conditions are quite unreliable as the rain appears to be swept along almost horizontally during the heavy rain-squalls of a tropical cyclone. This apparently explains why the instantaneous rates of tropical cyclone rainfall and non-tropical cyclone rainfall are comparable. Over longer periods, the tropical cyclone rainfall intensity will be lower than that due to thunderstorms or large scale surface convergence.

V. TROPICAL CYCLONES CROSSING TAIWAN

A tropical cyclone crossing Taiwan may not affect Hong Kong when only winds are considered. However, very often such a tropical cyclone gives rise to thunderstorms and heavy rain at Hong Kong. An example can be found in July 1965 after Tropical Storm Harriet had crossed Taiwan.

The frequency of tropical cyclones crossing Taiwan and then dissipating over the China mainland is only one per year. (During the last 80 years with records, only 76 tropical cyclones moved on such a track). Table 12 shows the mean daily rainfall recorded at the Royal Observatory due to such tropical cyclones.

Table 12. Mean Daily Rainfall at the Royal Observatory Due to Tropical Cyclones Crossing Taiwan (1884-1939, 1947-1970)

MONTH	Total No.of Occurrences	Mean Daily Rainfall on Specific Day(mm)							Total
		D-1	D	D+1	D+2	D+3	D+4	D+5	
JUN	1	44.1	63.7	131.8	82.8	25.5	39.3	Nil	387.2
JUL	21	6.6	17.5	36.5	31.0	18.9	11.8	12.2	134.5
AUG	34	3.8	12.5	30.6	23.0	20.5	24.8	13.9	129.1
SEP	17	1.3	3.0	17.6	10.4	2.1	Nil	Nil	34.4
OCT.	3	Nil	0.3	0.8	20.3	11.7	Nil	Nil	33.1
MEAN PER YEAR	1	4.4	11.9	29.5	23.1	17.6	16.4	12.7	115.6

In the above table, "D" is the day when the tropical cyclone enters the China Coast after crossing Taiwan. Normally (D-1) is the day when the tropical cyclone is crossing Taiwan.

Most of these tropical cyclones are found in August, and they rarely move on such a track in June or October. None have done so in May or during the dry months.

Rainfall becomes more intense at Hong Kong from the day the tropical cyclone crosses Taiwan until the second day after it has landed over the China mainland.

VI. TROPICAL CYCLONES OVER SOUTH CHINA SEA

It is quite certain that more rainfall can be expected from a tropical cyclone passing within 100 nautical miles of Hong Kong than one of equal intensity passing further away. Also, as already noted in Section III, a tropical cyclone causing a lower minimum hourly mean sea level pressure at the Royal Observatory would bring more rain to Hong Kong.

Even so, the accuracy of rainfall forecast for tropical cyclones is still low since there are too many factors governing the rainfall distribution and intensity of a tropical cyclone. The parameters can change very rapidly without our knowledge. That is why a tropical cyclone of typhoon intensity might sometimes bring less rain to Hong Kong than one of mere tropical depression intensity moving on a similar track or passing even further away from Hong Kong.

Good examples can be found in 1908 and 1970. In 1908 a typhoon virtually crossed Hong Kong on the morning of August 28. The total rainfall during the 5-day period August 27-31 was only 82.3 mm. In 1970, a tropical depression formed on August 1 about 120 nautical miles east of the southern tip of Taiwan over the Western Pacific. It landed the south China coast on August 2 about 180 nautical miles east of Hong Kong, maintaining the intensity of a tropical depression. The daily rainfall on August 2 and 3 were 82.6 mm and 140.9 mm respectively. The 5-day rainfall during August 2-6 amounted to 245.7 mm, about three times the amount brought by the typhoon in 1908.

Despite such difficulties in forecasting rainfall in connection with the approach of a tropical cyclone, it is necessary to have a guide that can be used for rainfall predictions. The mean areal distribution of rainfall associated with a tropical cyclone was derived for each month by computing the mean 24-hour rainfall amounts recorded at the Royal Observatory for specific locations of the tropical cyclones. The aim was to obtain a simple estimation or prediction of 24-hour rainfall at Hong Kong.

The area covers from latitude 10°N to 30°N and from longitude 105°E to 125°E. The area thus covers practically the whole South China Sea. This area is then divided into one-degree grids. Now, instead of elaborating on the mean hourly rainfall for each position of a tropical cyclone, the mean 24-hour rainfall was calculated for any specific location of the tropical cyclone.

A note of explanation is needed here. First of all, only the positions at 0000 hour G.M.T. were used to relate with the daily rainfall amounts measured on a calendar day. In this way, the relevant data can be easily extracted and the mean daily rainfall for each grid can be quickly computed. Strictly speaking, the mean daily rainfall plotted on a particular grid refers only to the amount expected when a tropical cyclone is centred at this position at 0000 hour G.M.T. However, when isohyets are used for interpolation of rainfall, the value read from the specific position may be reckoned as the amount expected at the Royal Observatory during the next 24 hours. The discrepancy of a few hours should lead to only a small error.

Secondly, no discrimination of tracks or specific movements of the tropical cyclones has been attempted. Instead, since the rainfall distribution in association with a tropical cyclone occurring in each month may not be the same, separate diagrams were done for the months May to November. Another was done for all the dry months December through April.

The diagrams of mean 24-hour rainfall distribution in connection with tropical cyclones for each month are given in Figure 14(a) to 14(h). It is noted that the patterns are not at all the same.

In May, the maximum rainfall area is found just west of Hong Kong. (Figure 14(a)) The pattern is the same in June as seen in Figure 14(b). Gradients of rainfall intensity are steep towards the east in both months.

In July as seen in Figure 14(c), the maximum rainfall area shifts to the north of Hong Kong, and the rainfall gradients slacken slightly, though still steep towards the east. The maximum centre is again located to the west of Hong Kong in August as given in Figure 14(d). Rainfall gradients towards the east are less steep than those for May.

The patterns for September and October as seen in Figures 14(e) and 14(f) are more or less the same. The mean 24-hour distribution of tropical cyclone rainfall for the month of November and for the months December through to April are given in Figures 14(g) and 14(h). Data is sparce in the vicinity of Hong Kong in these two diagrams as very few tropical cyclones have passed so close to Hong Kong during the winter months when strong north easterly monsoon winds prevail.

It should be borne in mind that these diagrams will only enable a quick estimation of rainfall for tropical cyclones centred over the South China Sea. They do not necessarily represent a true picture of the areal distribution of rainfall intensities for a model tropical cyclone over the sea.

VII. SUMMARY

This paper has given a statistical study of the mean rainfall distribution with a tropical cyclone that passed within 300 nautical miles of Hong Kong. More detailed analysis has been devoted to those tropical cyclones which passed within 100 nautical miles of Hong Kong. A simple estimation of rainfall expected at the Royal Observatory with tropical cyclones centred over the South China Sea for each month has also been attempted.

It is seen in Section III that the distance and direction of approach to Hong Kong of a tropical cyclone can be good indicators of rainfall expected locally. Pressure anomaly is another good rainfall predicator. The relationship of the intensity of a tropical cyclone and the rainfall distribution has not been considered in this study, but it looks likely that the intensity of a tropical cyclone may have little relationship with the rainfall amount recorded at the Royal Observatory. There are many examples that a tropical cyclone of the intensity of a tropical storm often brought more rain to Hong Kong than one of typhoon intensity when their tracks and other meteorological elements were similar. In July 1911, a typhoon landed less than 30 nautical miles west of Hong Kong and the "total" tropical cyclone rainfall recorded at the Royal Observatory was only 40 mm while the rainfall produced by Severe Tropical Storm Lola moving on a similar course in July 1966 amounted to about 200 mm.

There are still many uncertain meteorological parameters. In order to achieve more accurate forecast of tropical cyclone rainfall, more attention needs to be given to analysing the effects of all the variables.

VIII. ACKNOWLEDGEMENT

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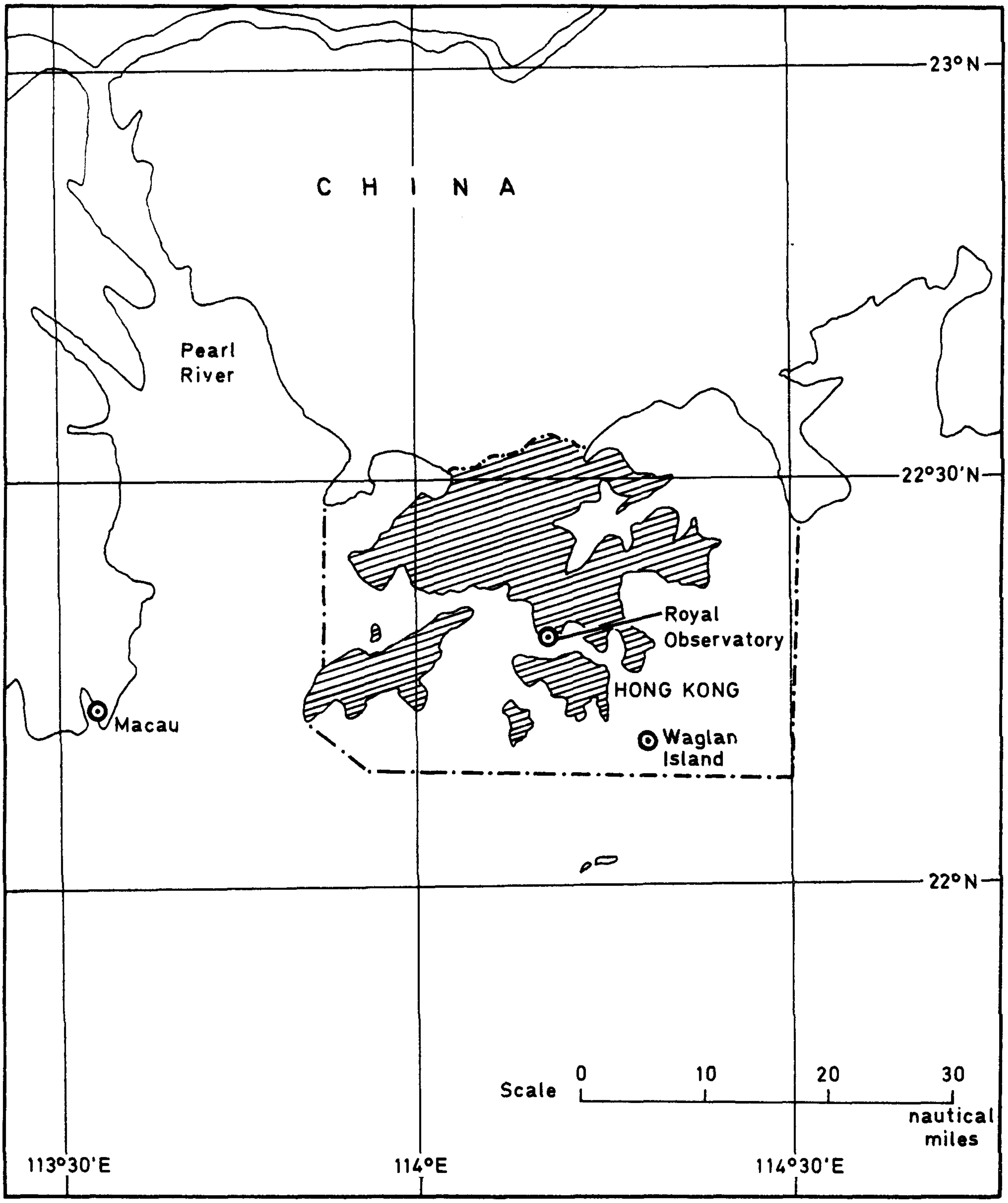


Positions: (a) Royal Observatory: 22°18'N 114°10'E

(b) Waglan Island : 22°11'N 114°18'E

(about 10 nautical miles southeast of R.O.)

(c) Macau: 22°12'N 113°32'E

(about 40 nautical miles west of R.O.)

Fig. 1 MAP OF HONG KONG, MACAU AND WAGLAN ISLAND.

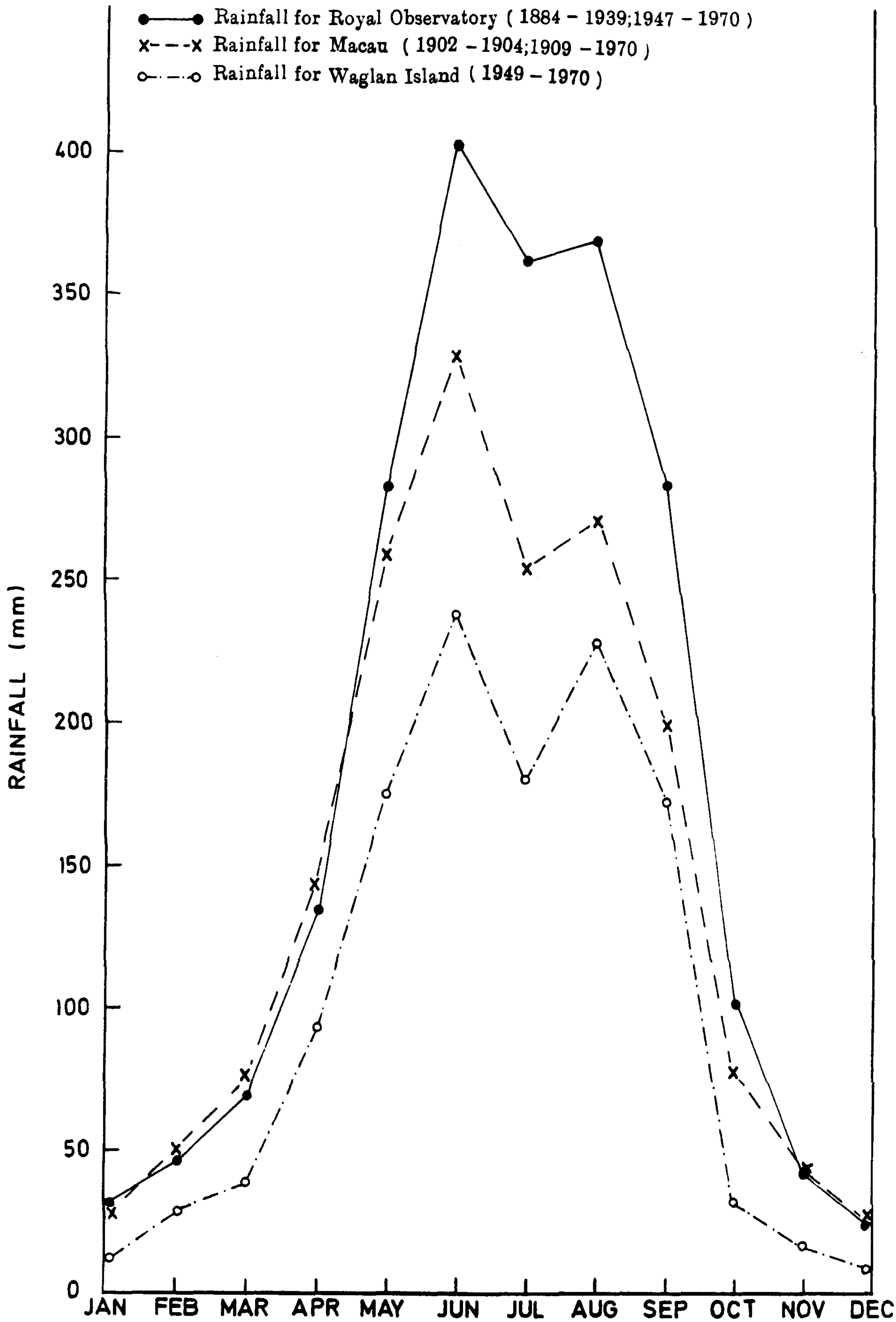


Fig. 2 MEAN MONTHLY RAINFALL FOR ROYAL OBSERVATORY, MACAU, AND WAGLAN ISLAND

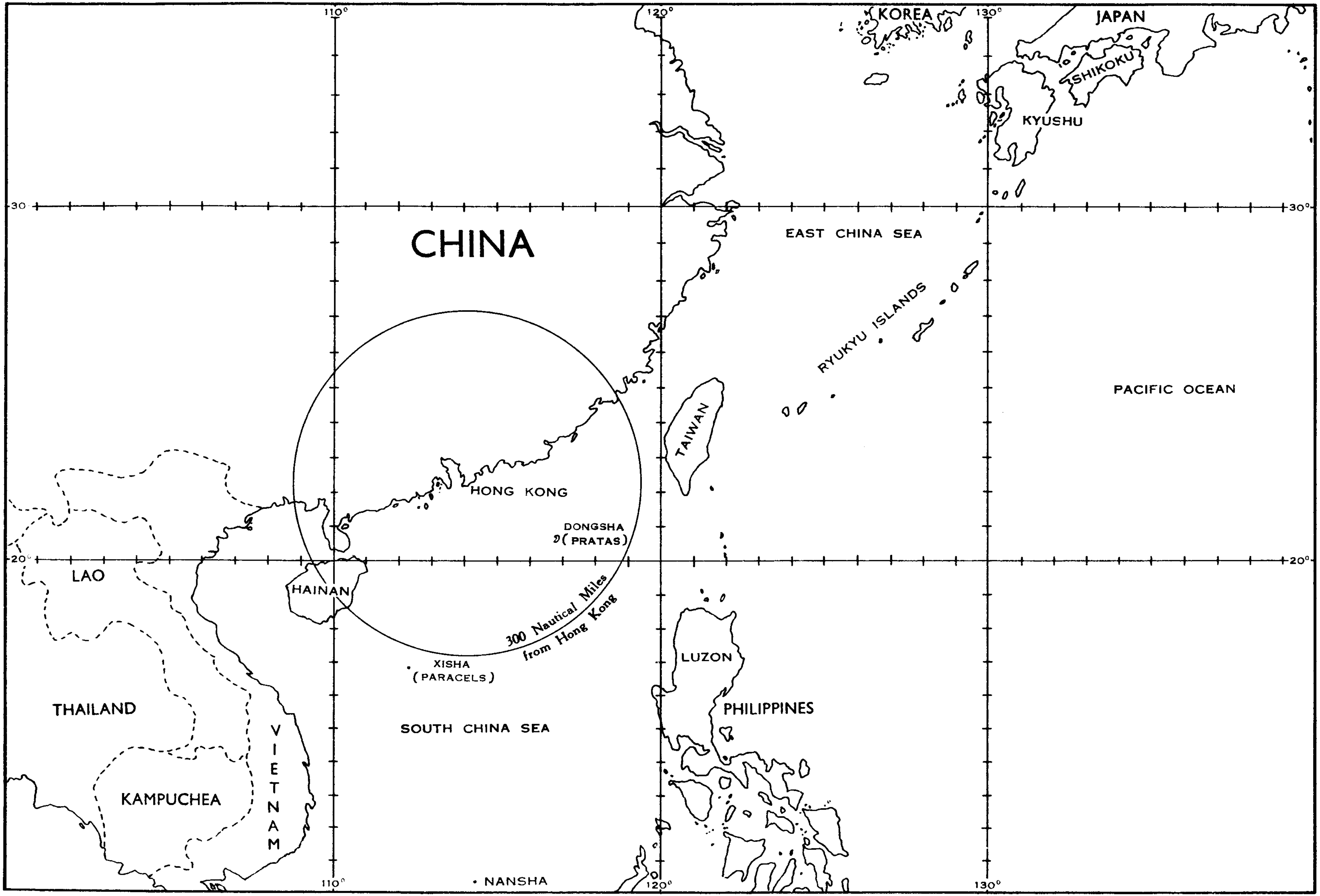


Fig. 3 MAP OF SOUTH CHINA

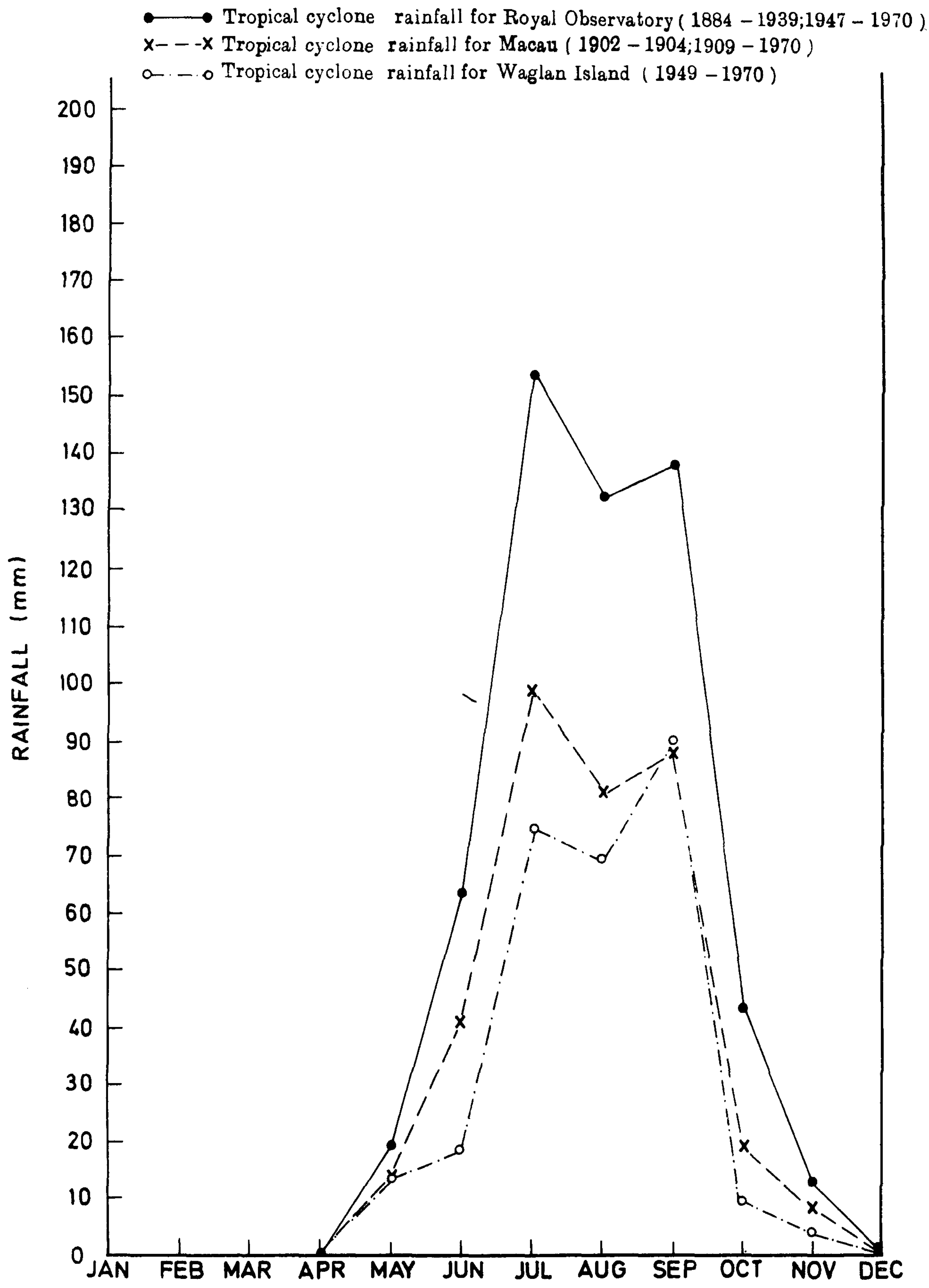


Fig. 4 MEAN MONTHLY TROPICAL CYCLONE RAINFALL FOR ROYAL OBSERVATORY, MACAU, AND WAGLAN ISLAND

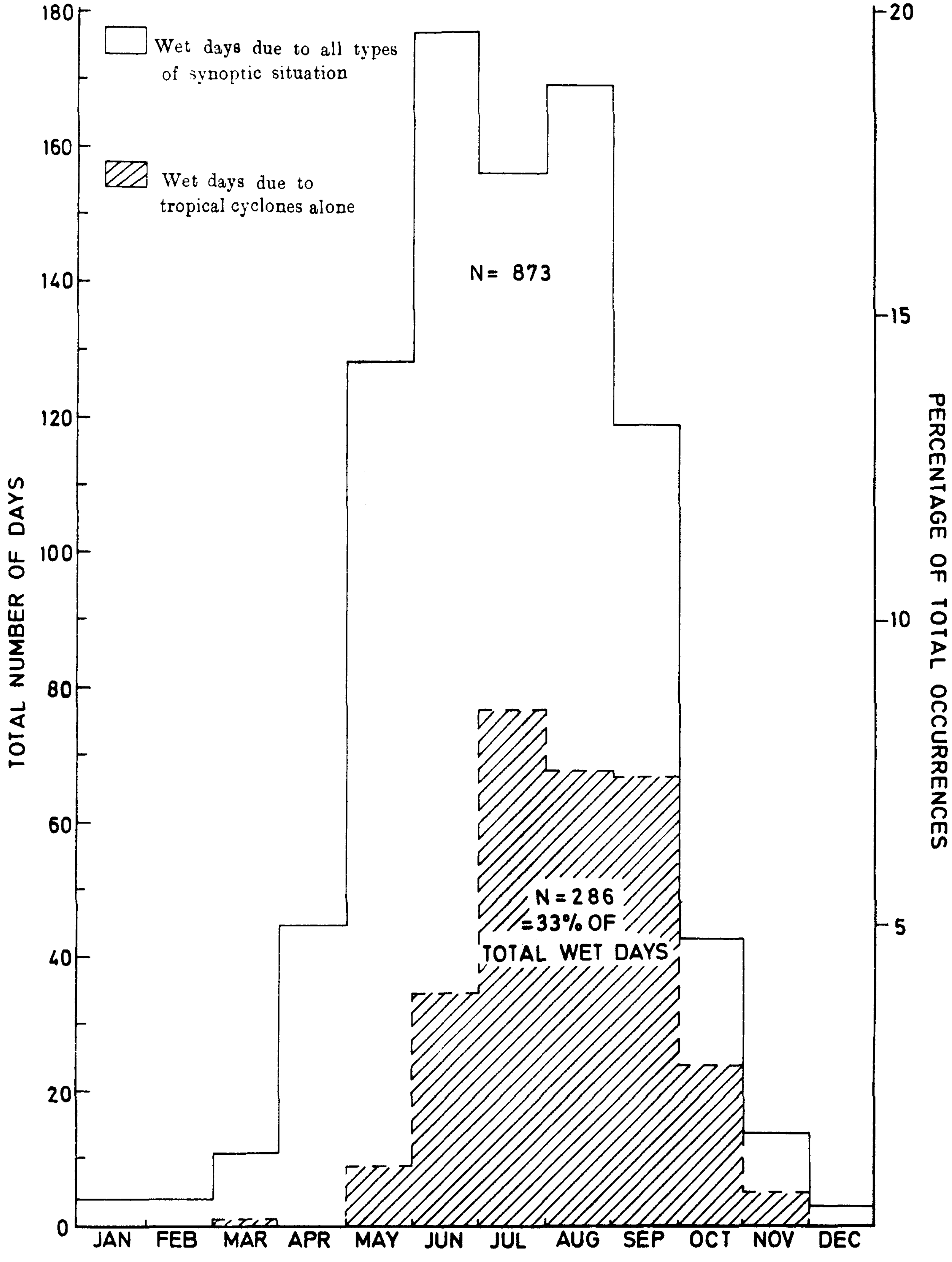


Fig. 5 COMPARISON OF OCCURRENCES OF WET DAYS (DAILY RAINFALL ≥ 50 MM) DUE TO ALL TYPES OF SYNOPTIC SITUATION WITH THOSE DUE TO TROPICAL CYCLONES ALONE (1884-1939, 1947-1970)

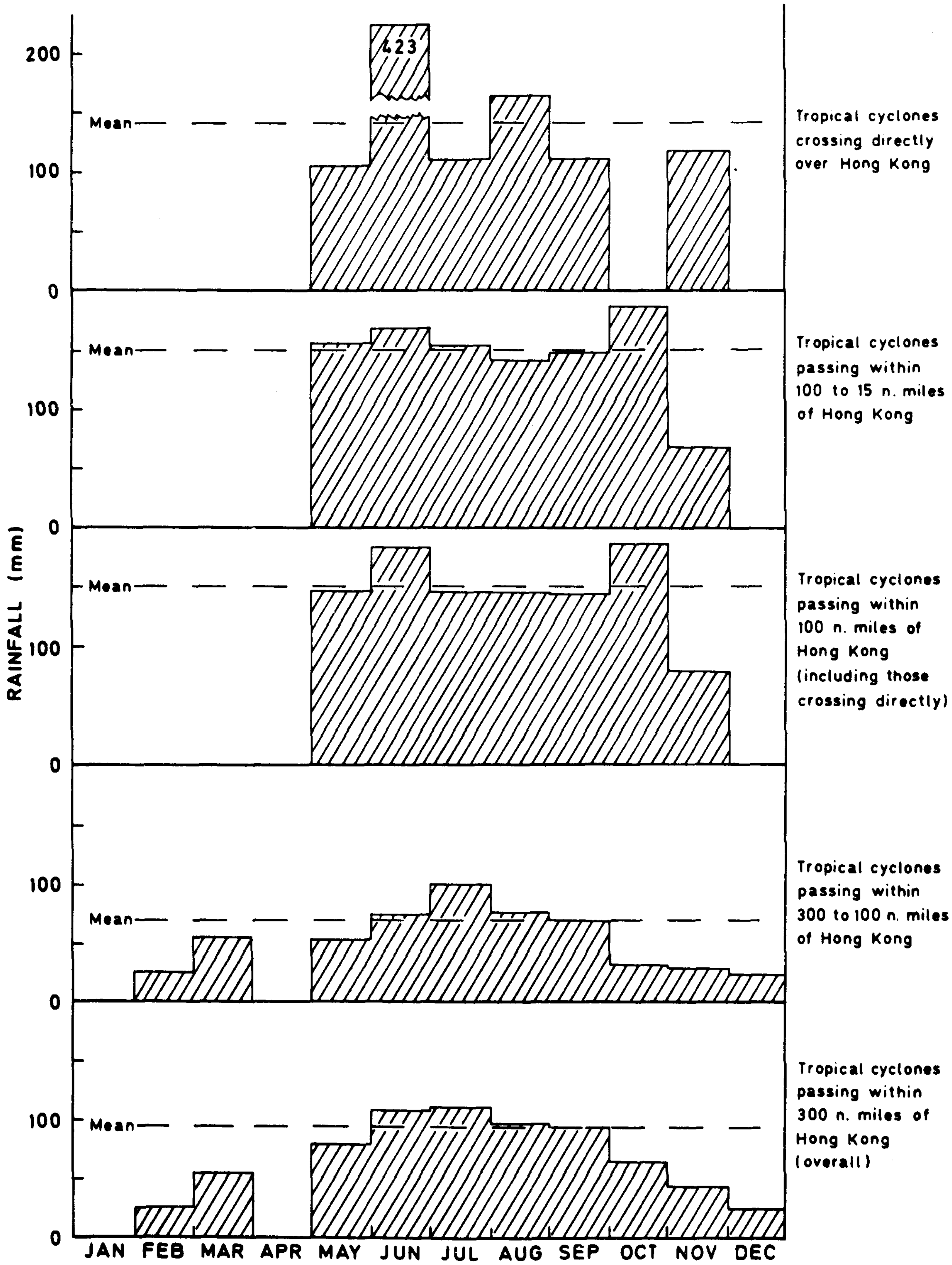


Fig. 6 MONTHLY VARIATIONS OF MEAN RAINFALL BY TROPICAL CYCLONES AT DIFFERENT RANGES OF DISTANCE FROM HONG KONG (1884-1939; 1947-1970)

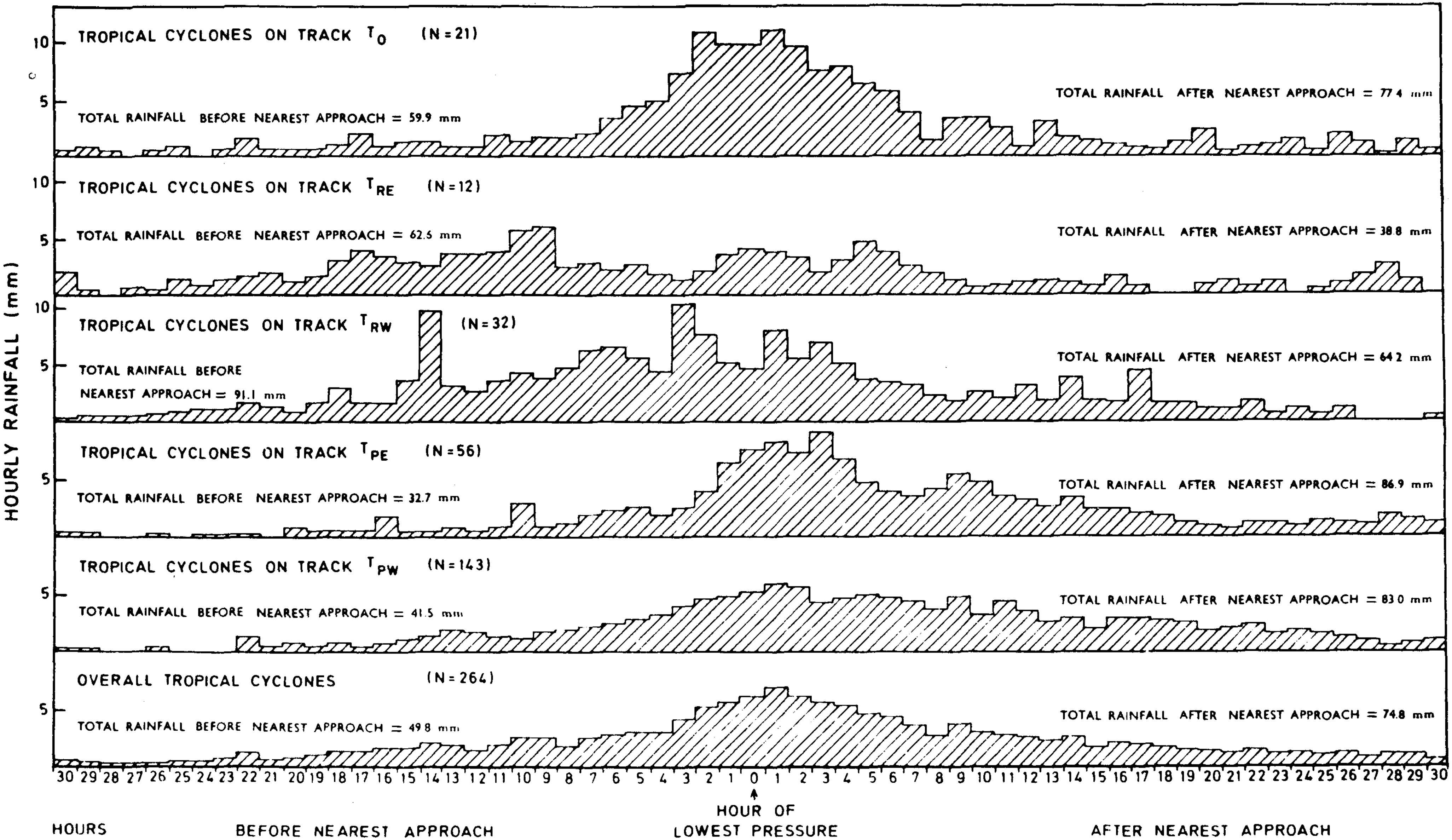


Fig. 7 MEAN HOURLY RAINFALL PROFILES FOR TROPICAL CYCLONES PASSING WITHIN 100 NAUTICAL MILES OF HONG KONG (1884–1939, 1947–1971)

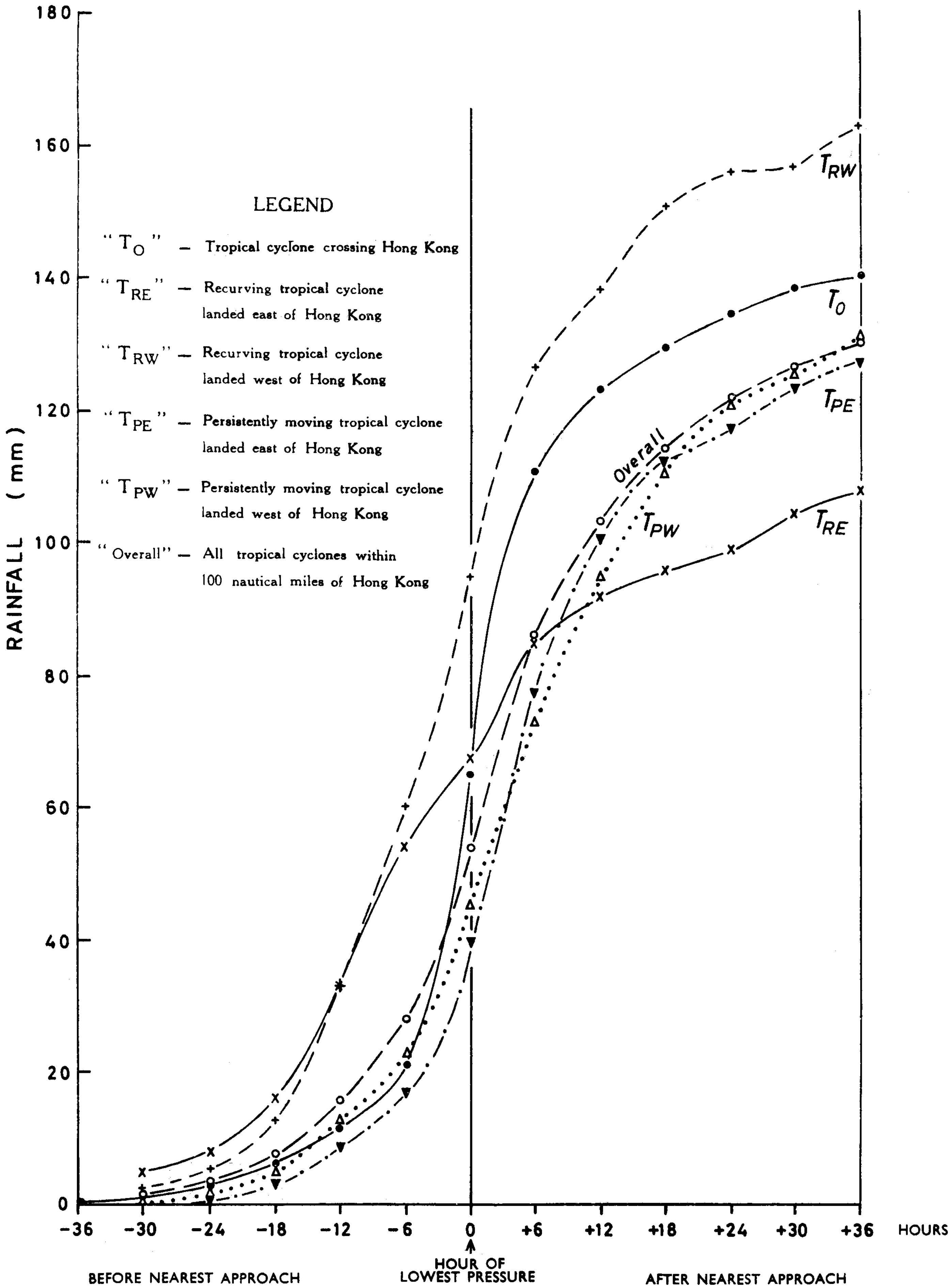


Fig. 8 MEAN ACCUMULATED RAINFALL PROFILE FOR TROPICAL CYCLONES PASSING WITHIN 100 NAUTICAL MILES OF HONG KONG (1884–1939, 1947–1971)

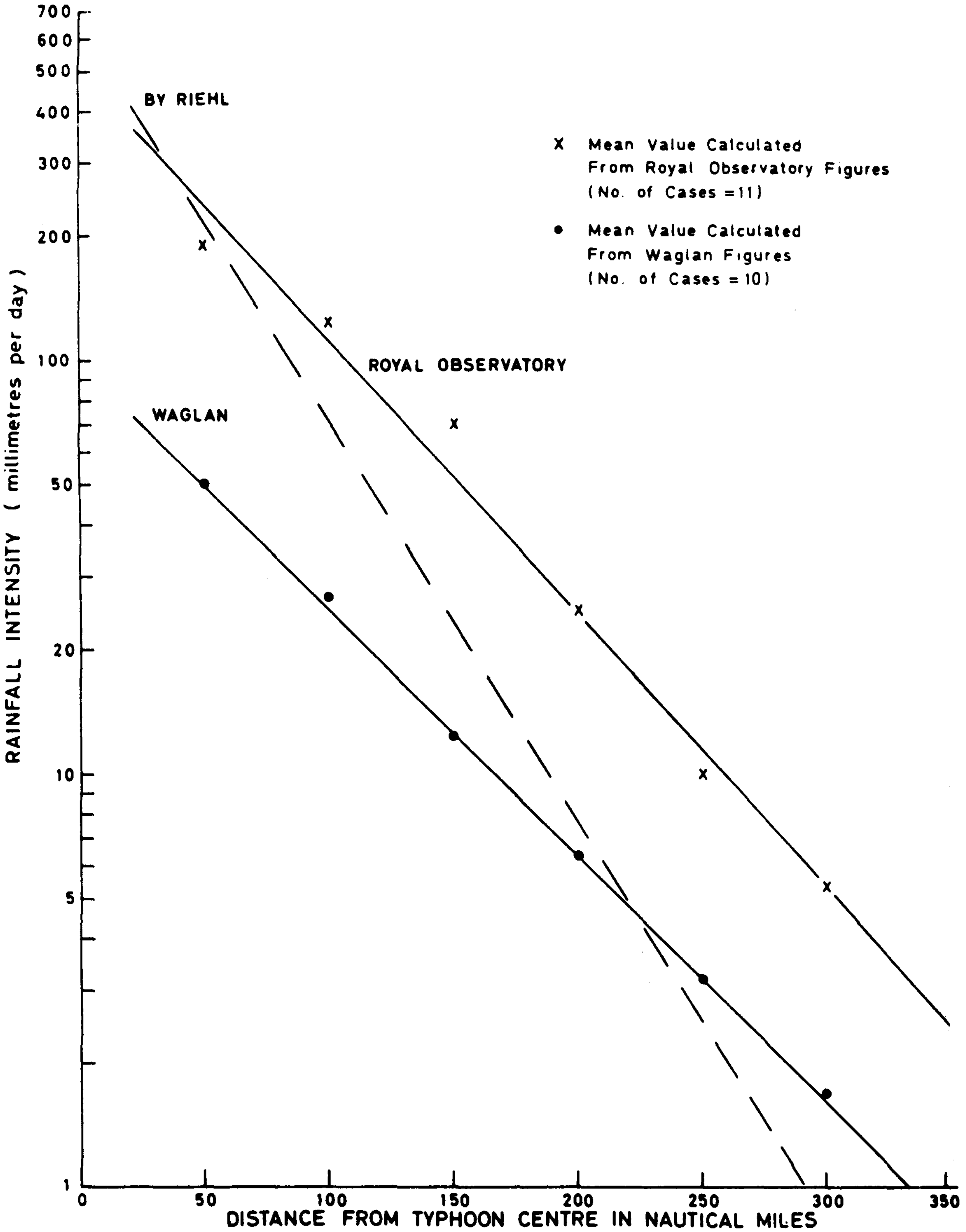


Fig. 9 RAINFALL INTENSITY WITH DISTANCE FROM TYPHOON CENTRE

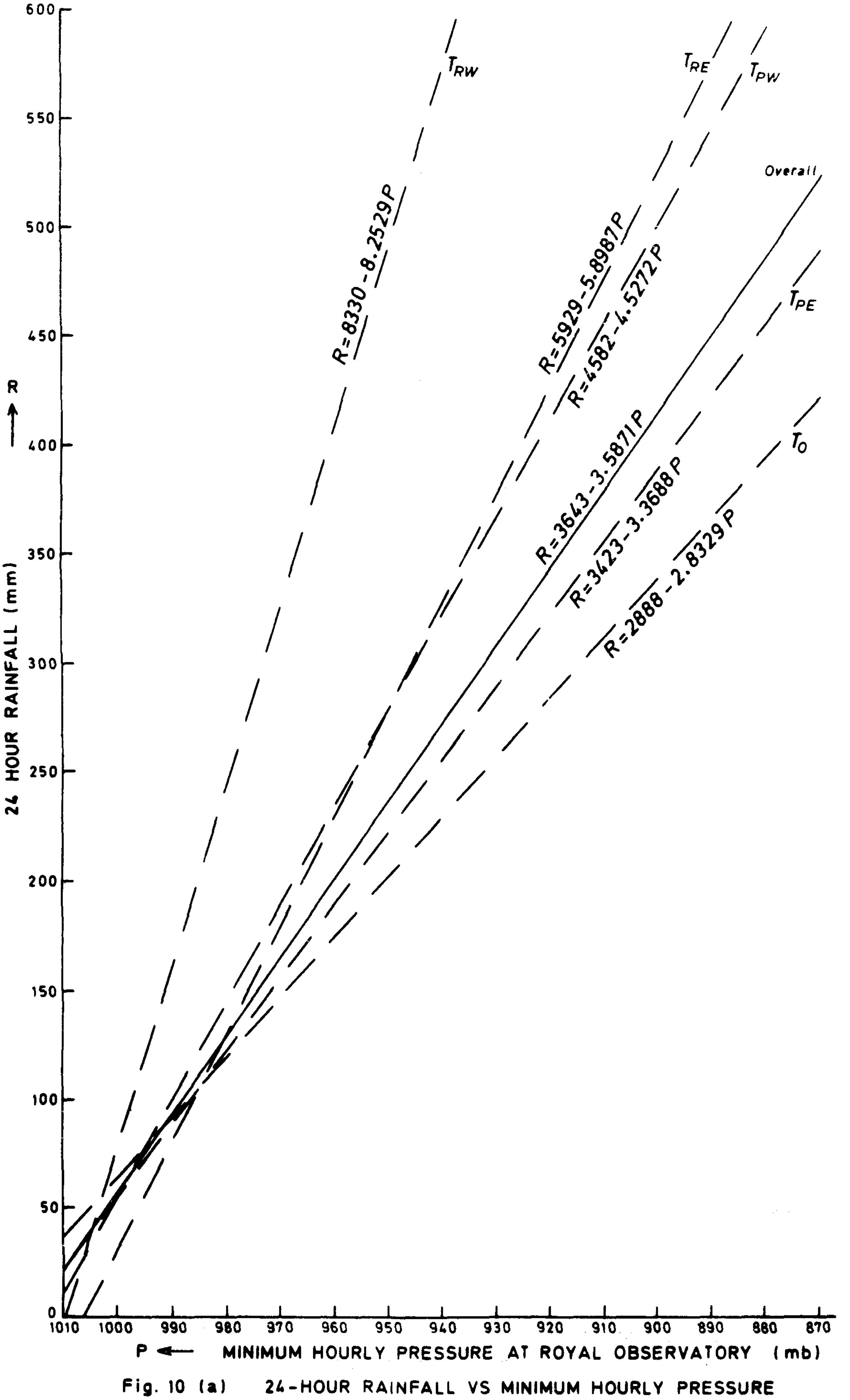


Fig. 10 (a) 24-HOUR RAINFALL VS MINIMUM HOURLY PRESSURE AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES PASSING WITHIN 100 NAUTICAL MILES OF HONG KONG

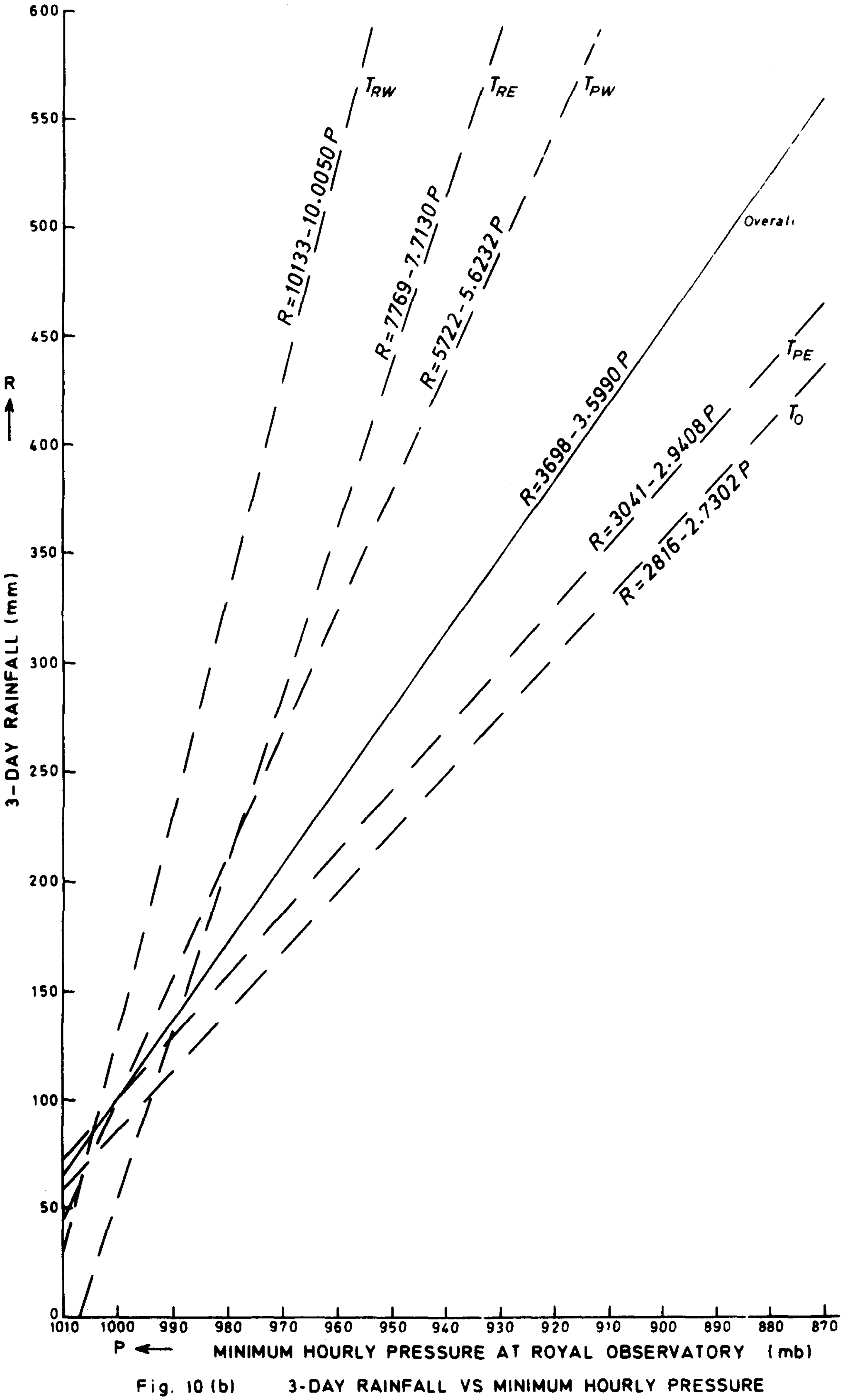


Fig. 10 (b) 3-DAY RAINFALL VS MINIMUM HOURLY PRESSURE AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES PASSING WITHIN 100 NAUTICAL MILES OF HONG KONG

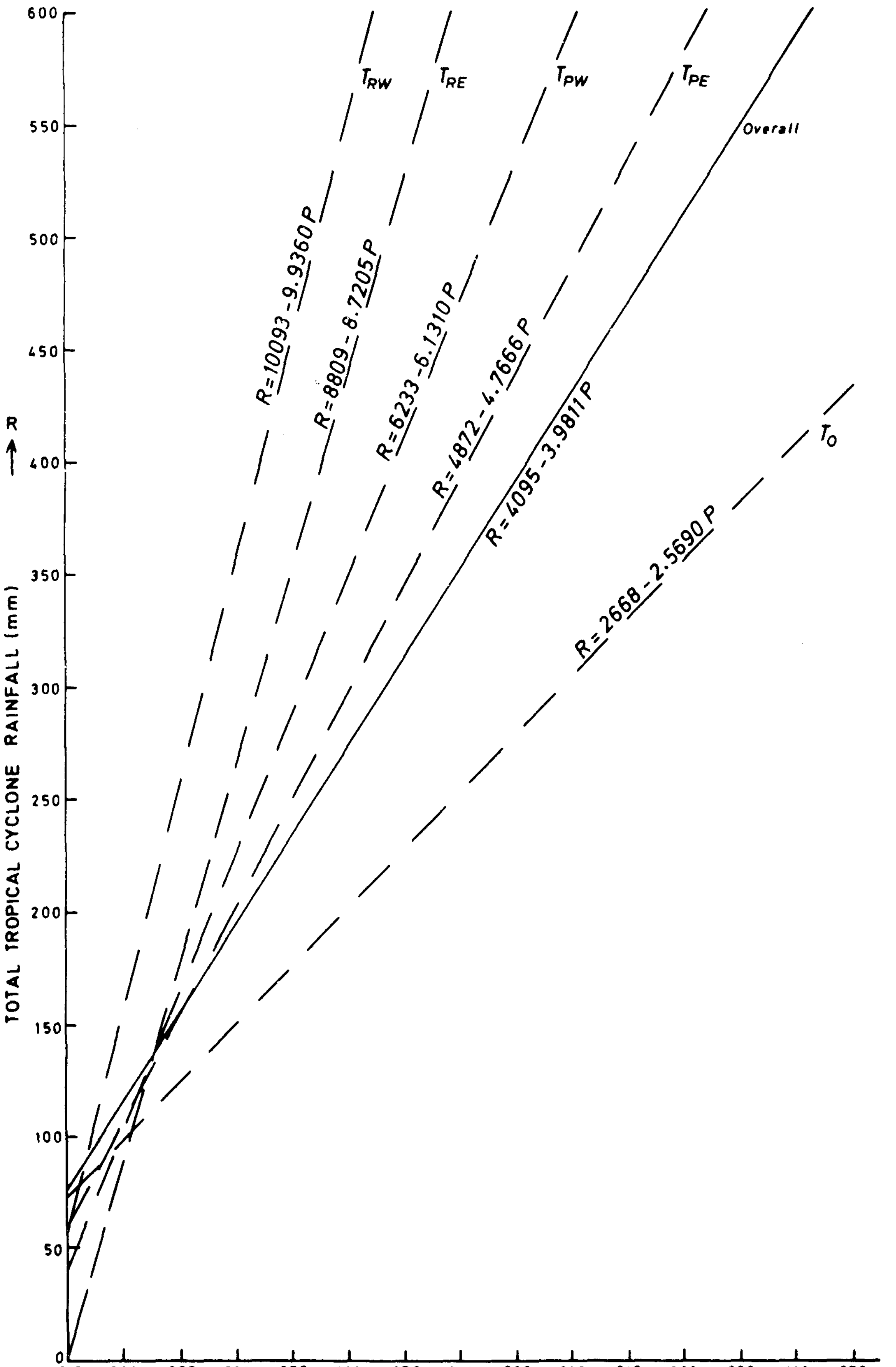


Fig. 10 (c) "TOTAL TROPICAL CYCLONE RAINFALL" VS MINIMUM HOURLY PRESSURE AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES PASSING WITHIN 100 NAUTICAL MILES OF HONG KONG

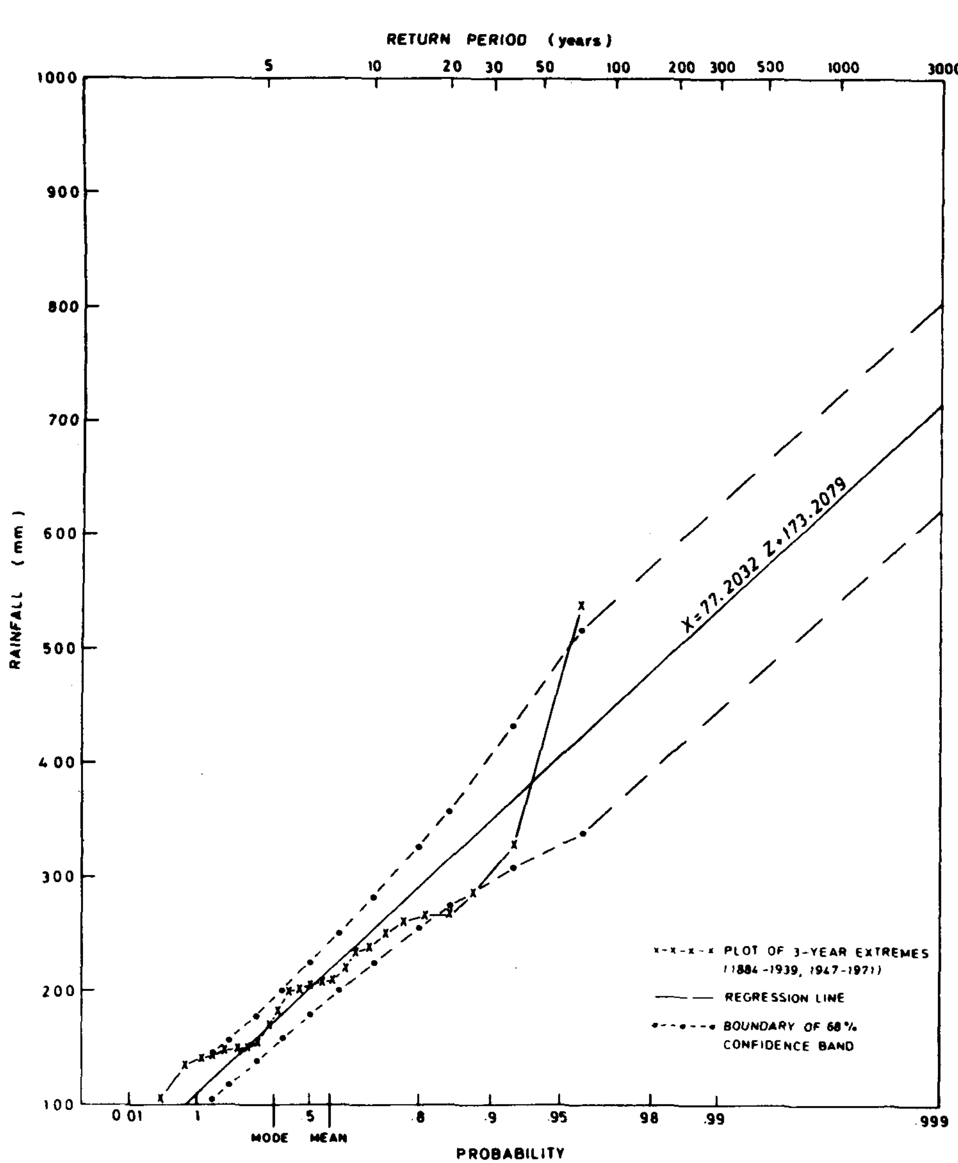


Fig 11 (a) PROBABILITY OF ANNUAL EXTREME DAILY RAINFALL DUE TO TROPICAL CYCLONES PASSING WITHIN 300 NAUTICAL MILES OF HONG KONG

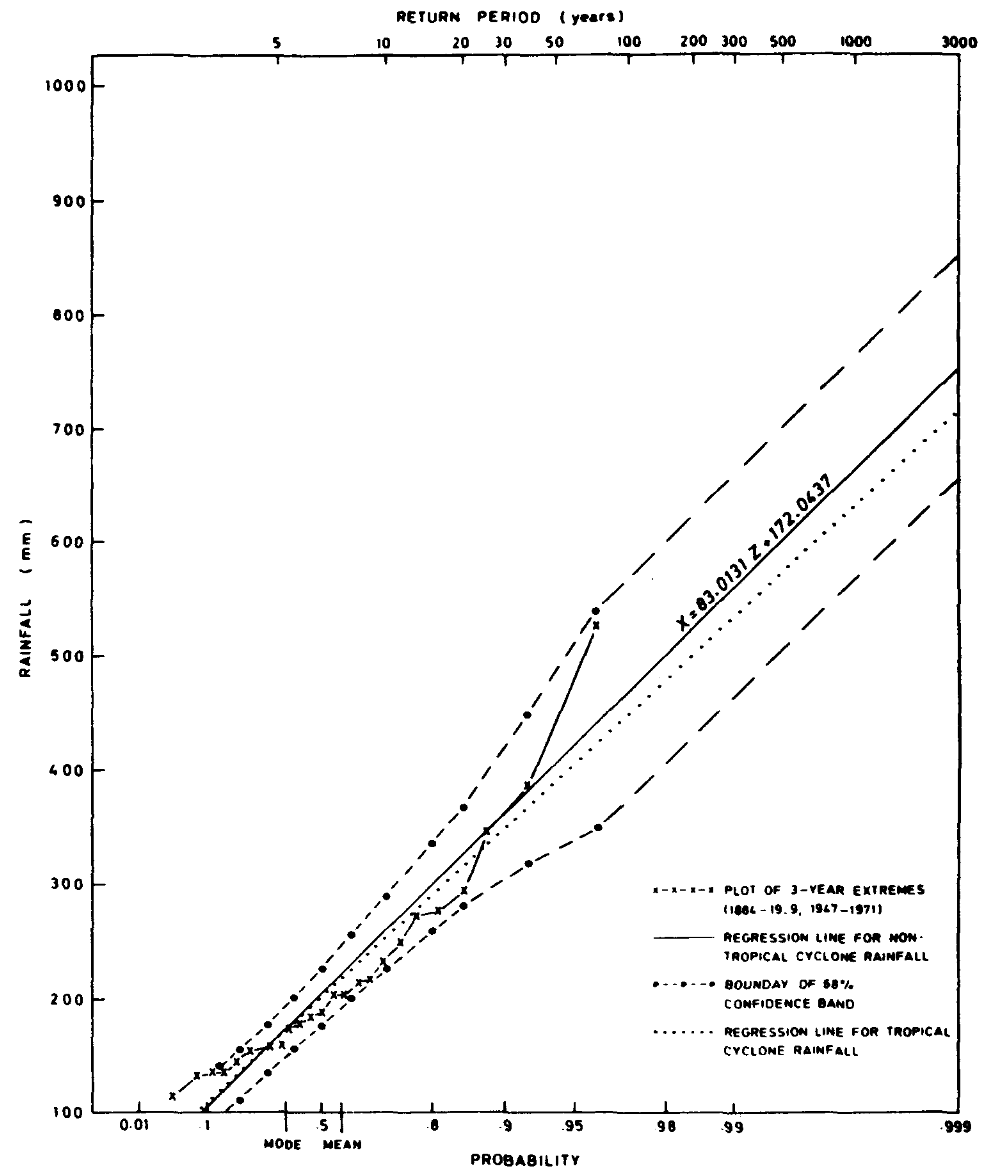


Fig. 11 (b) PROBABILITY OF ANNUAL EXTREME DAILY NON-TROPICAL CYCLONE RAINFALL

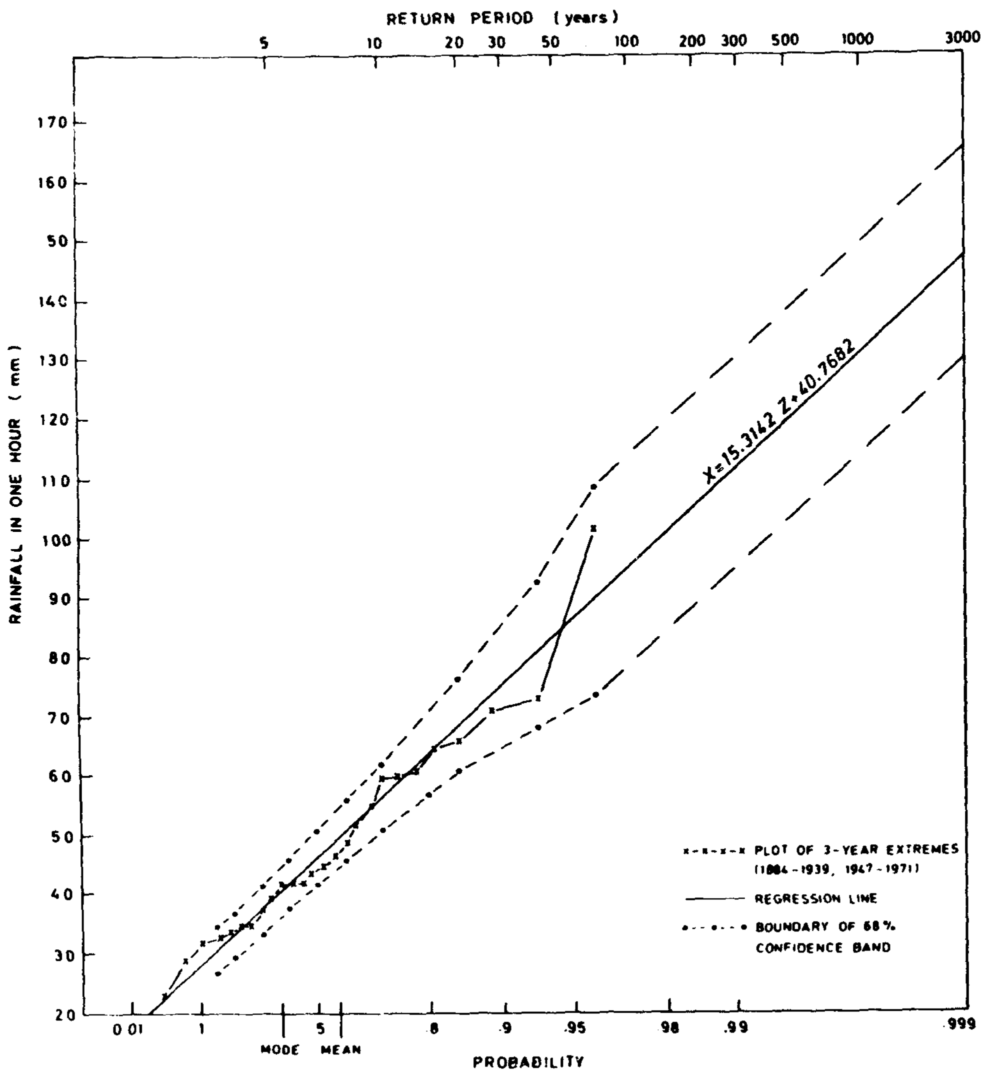


Fig. 12 (a) PROBABILITY OF ANNUAL EXTREME HOURLY RAINFALL DUE TO TROPICAL CYCLONES PASSING WITHIN 300 NAUTICAL MILES OF HONG KONG

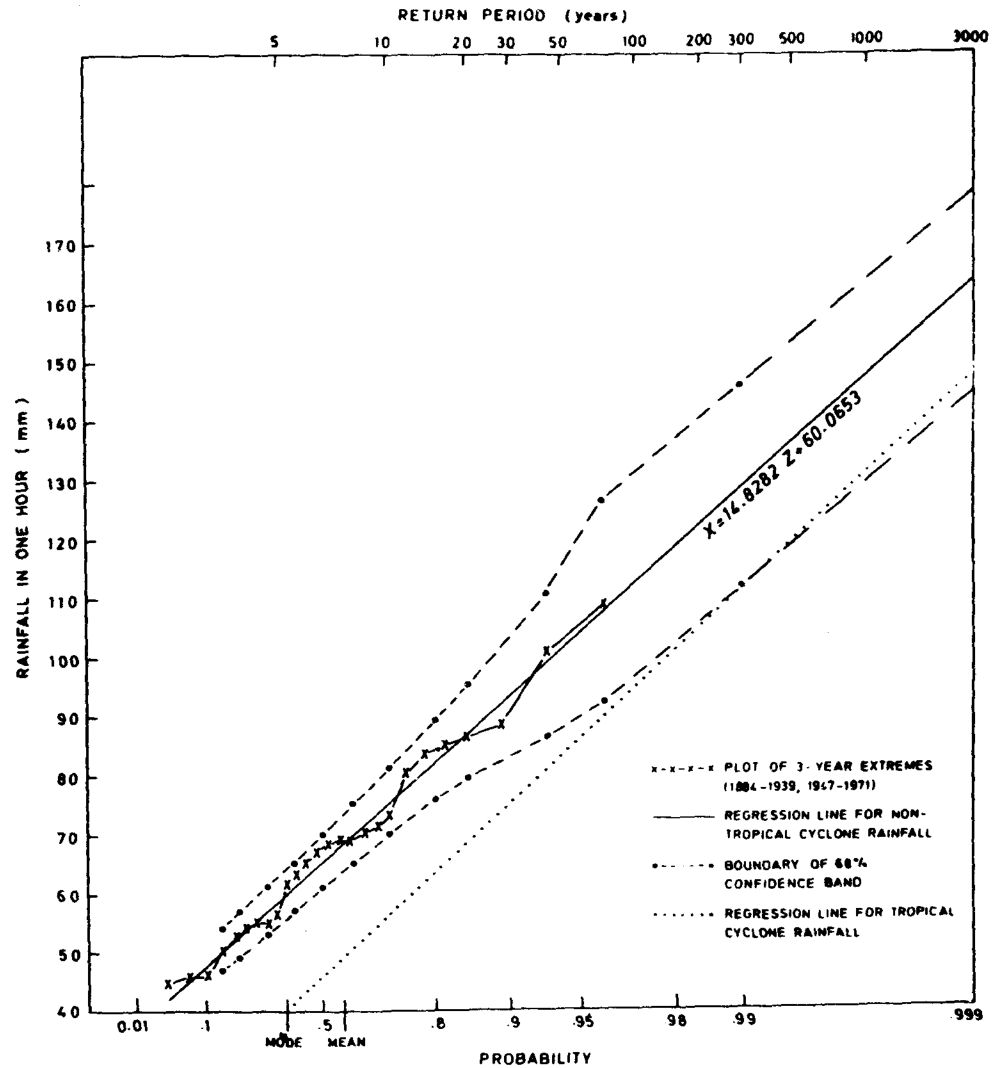


Fig. 12 (b) PROBABILITY OF ANNUAL EXTREME HOURLY NON-TROPICAL CYCLONE RAINFALL

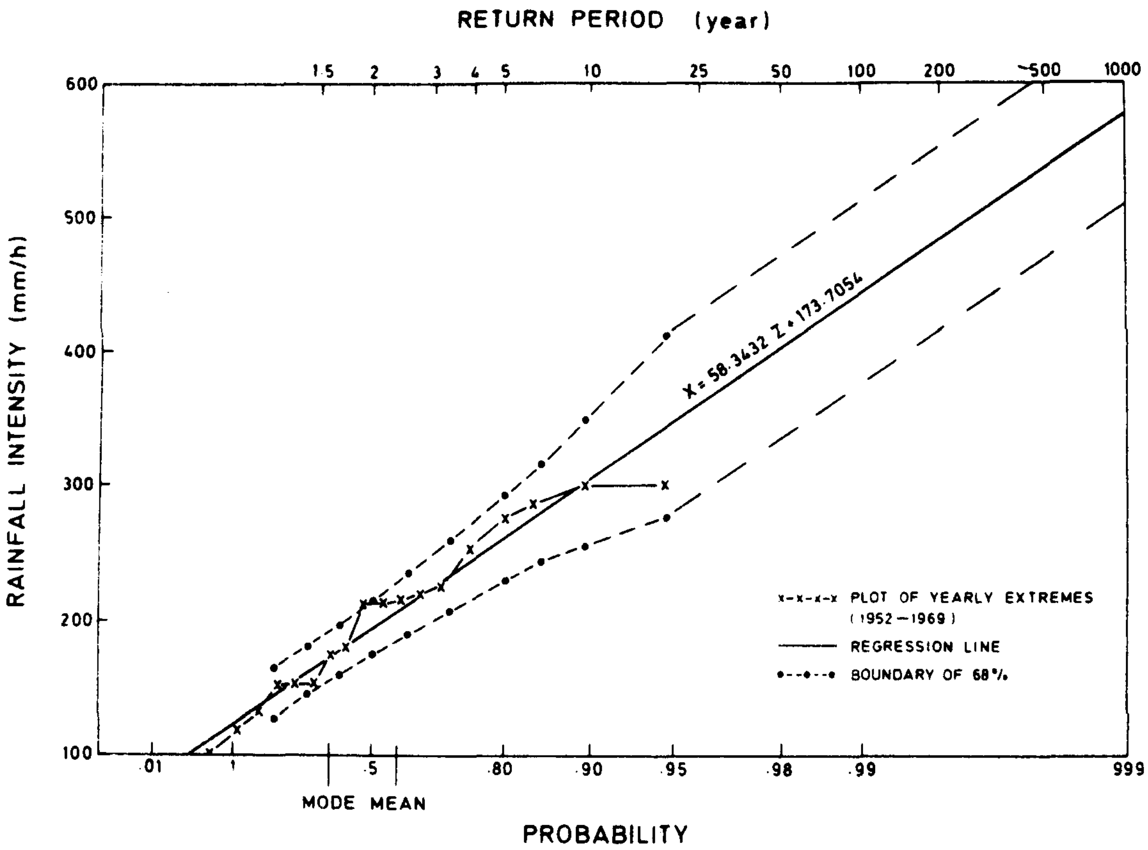


Fig. 13 (a) PROBABILITY OF ANNUAL EXTREME INSTANTANEOUS RATE OF RAINFALL DUE TO TROPICAL CYCLONES PASSING WITHIN 300 NAUTICAL MILES OF HONG KONG

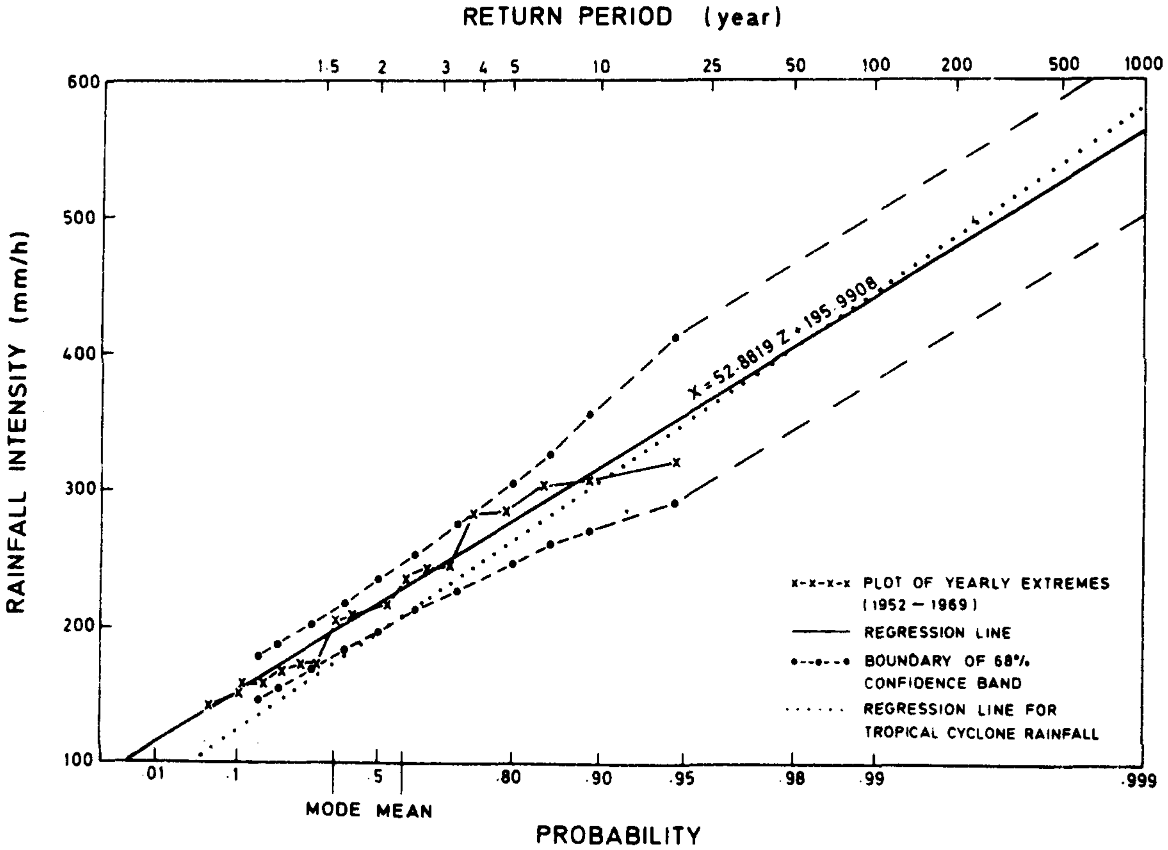


Fig. 13 (b) PROBABILITY OF ANNUAL EXTREME INSTANTANEOUS RATE OF RAINFALL (NON-TROPICAL CYCLONE RAINFALL)

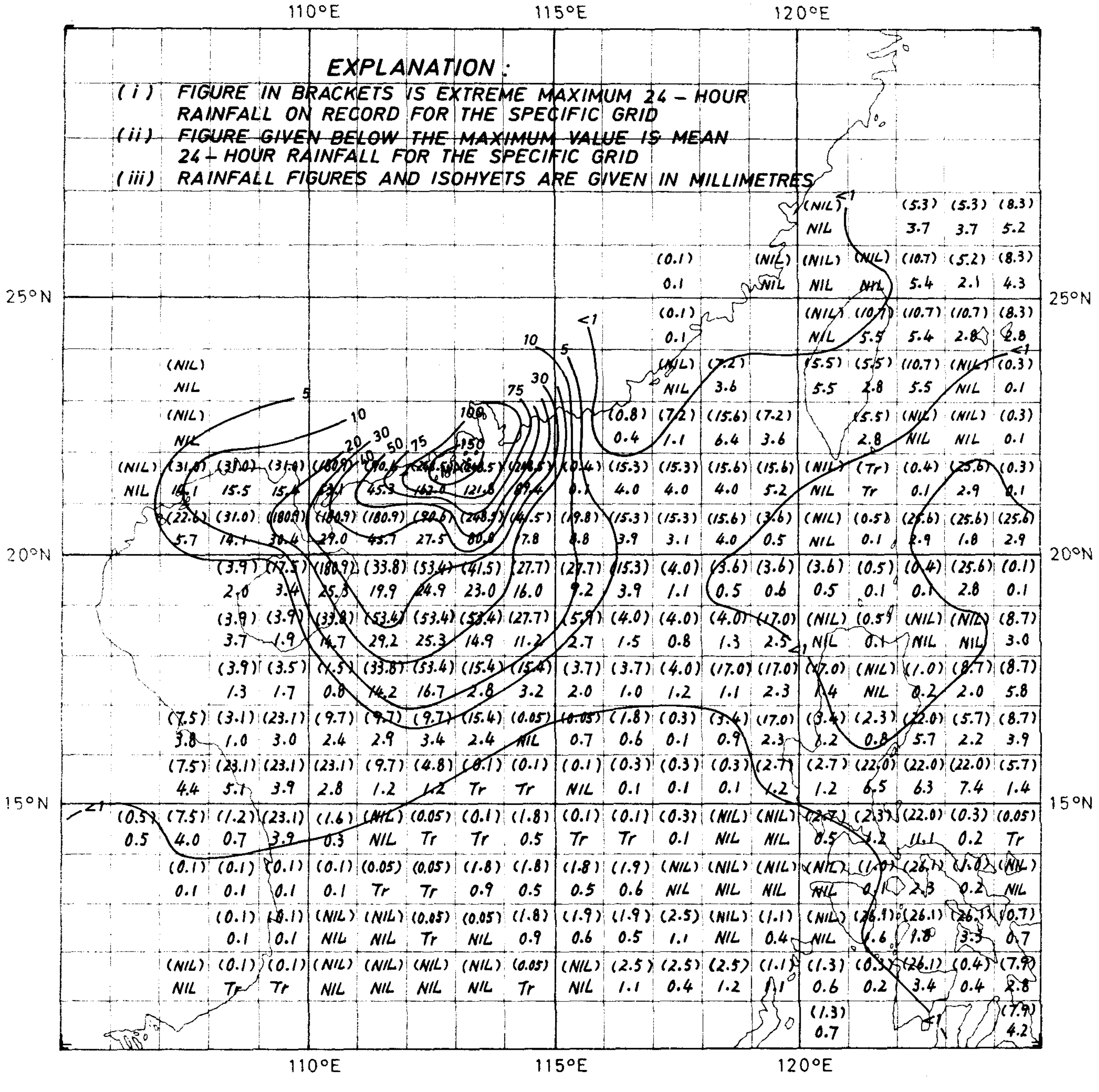


Fig. 14 (a) MEAN 24 - HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN MAY (1884 - 1939, 1947 - 1970)

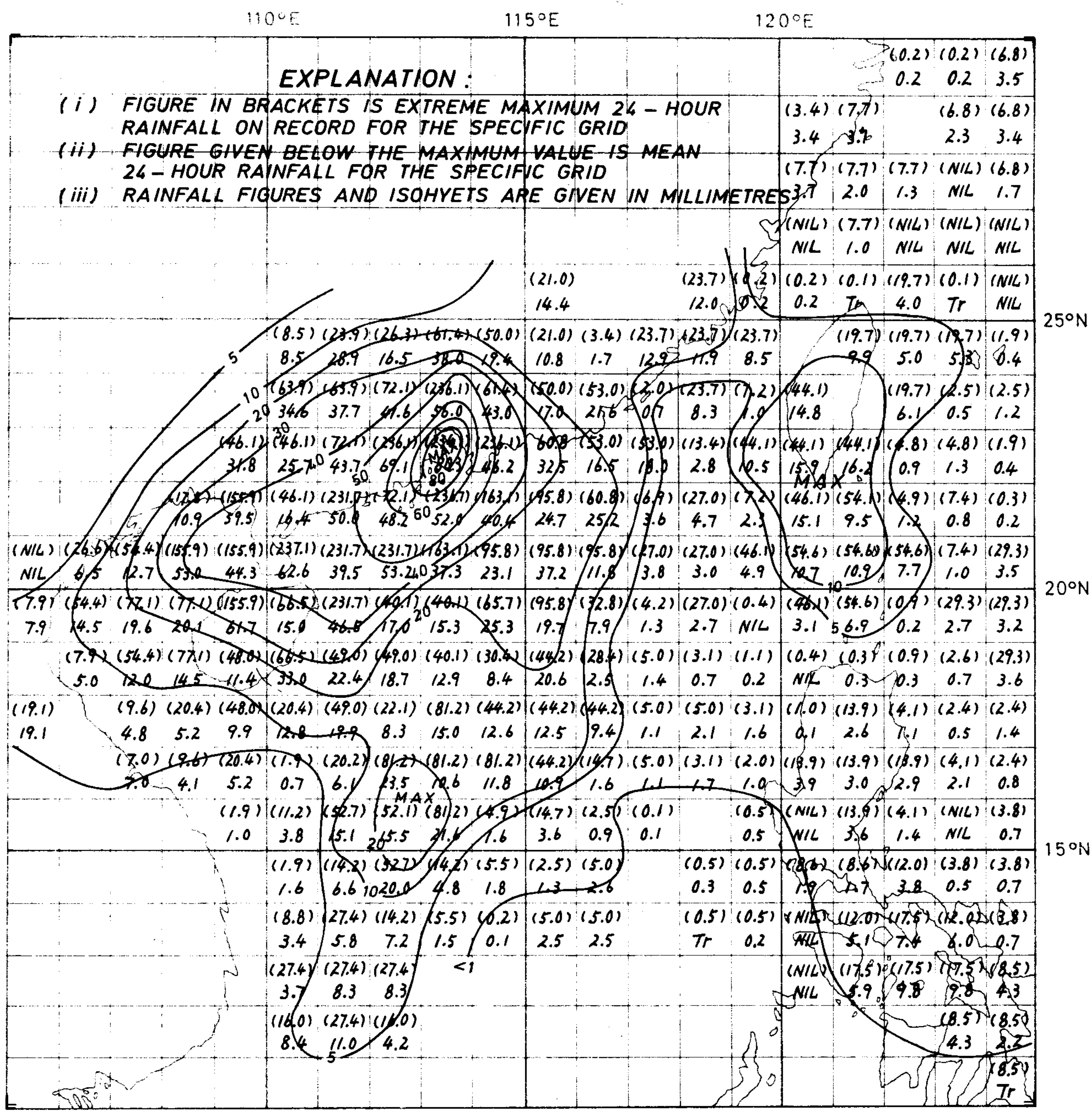


Fig. 14 (b) MEAN 24 – HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN JUNE (1884 – 1939, 1947 – 1970)

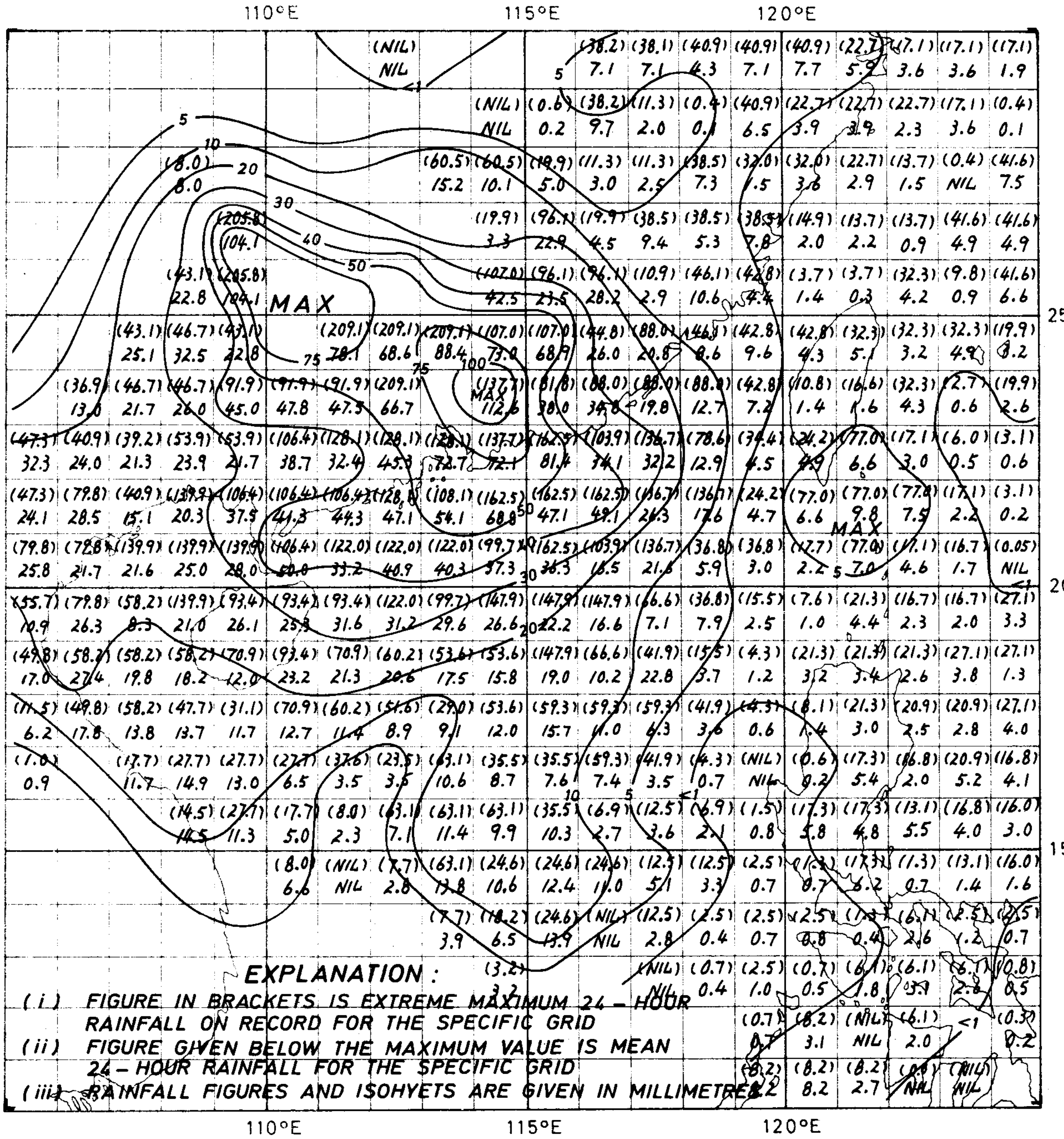


Fig. 14 (c) MEAN 24 – HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN JULY (1884 – 1939, 1947 – 1970)

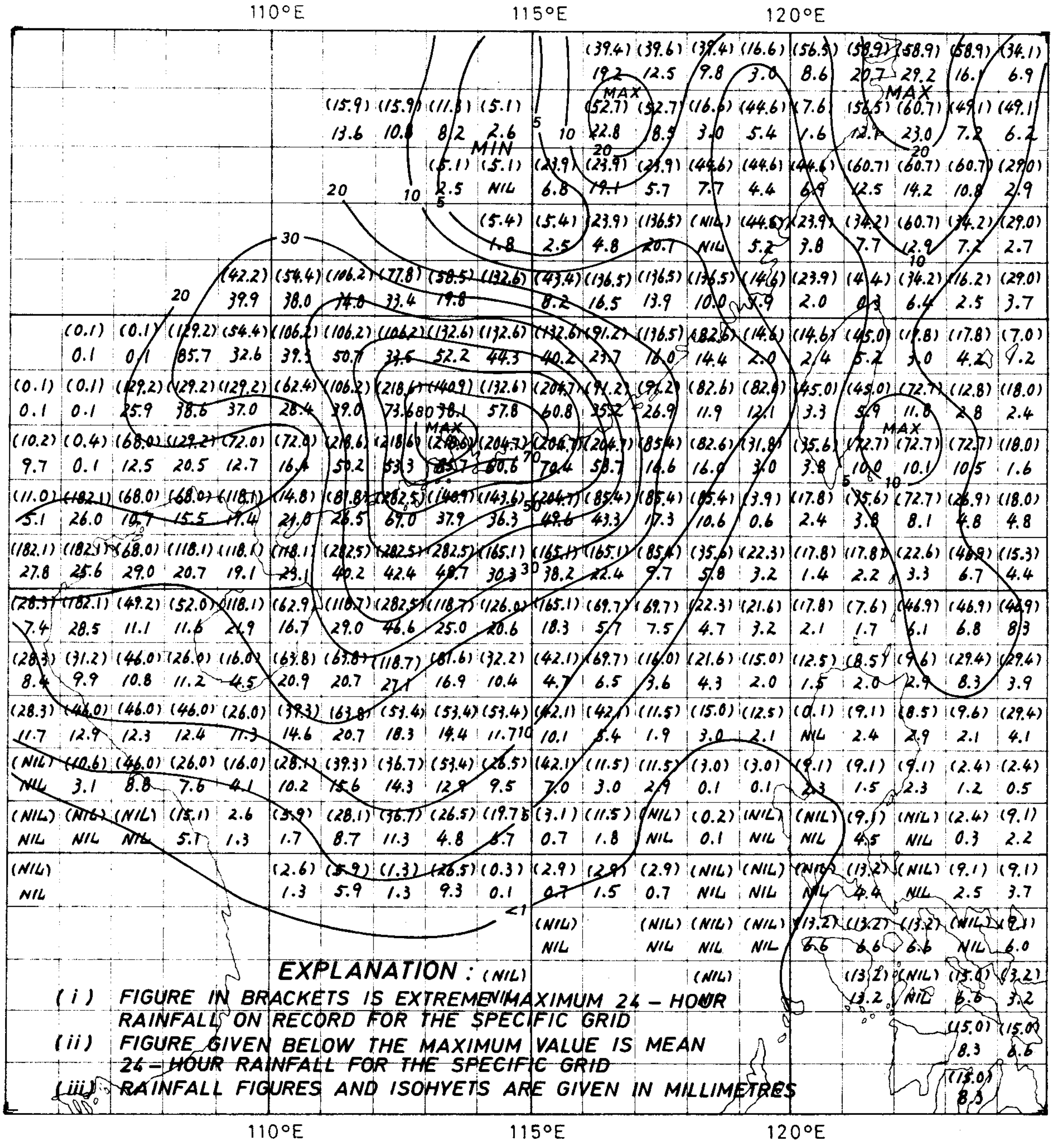


Fig. 14 (d) MEAN 24 - HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN AUGUST (1884 - 1939, 1947 - 1970)

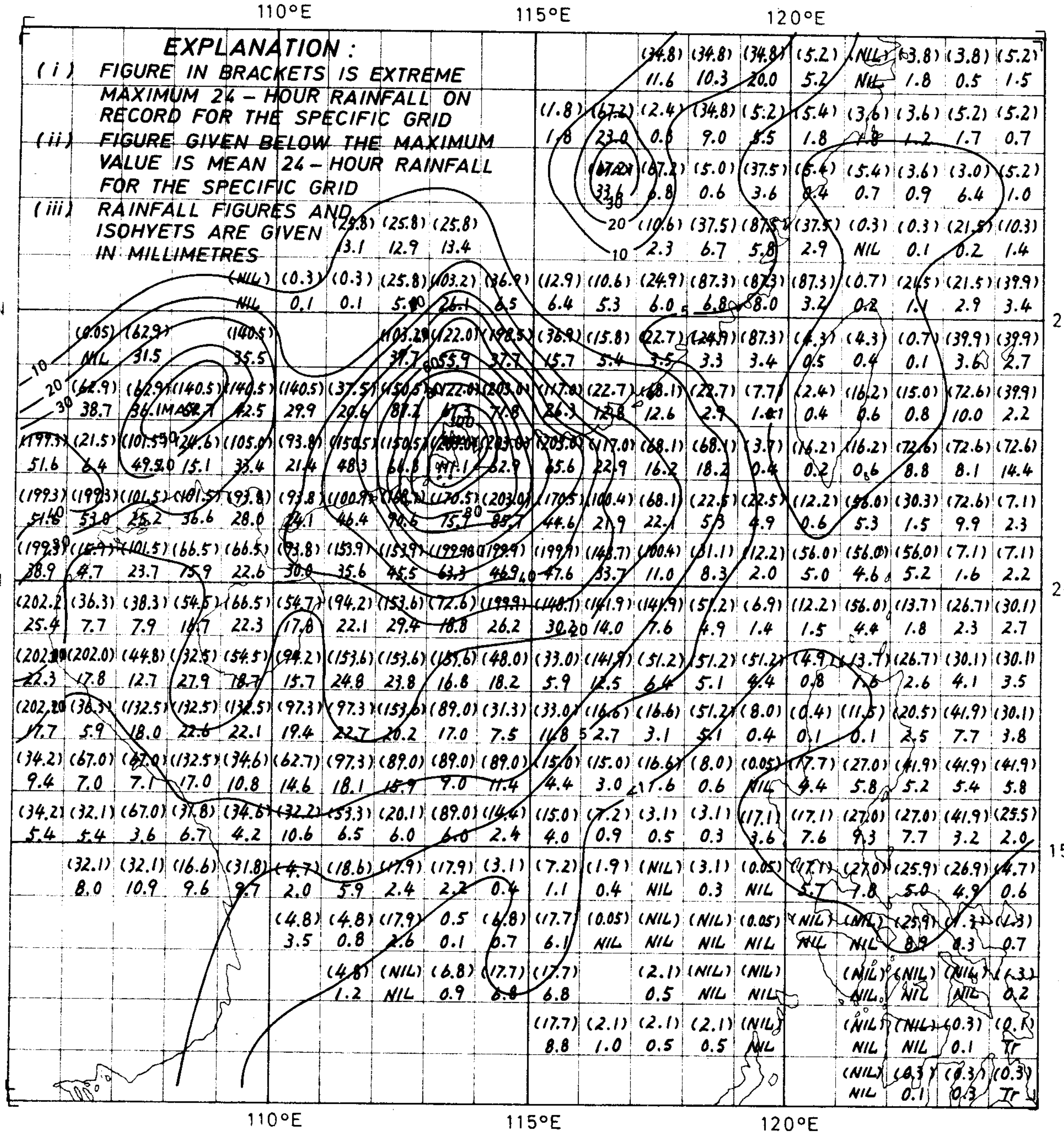


Fig. 14 (e) MEAN 24 - HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN SEPTEMBER (1884 - 1939, 1947 - 1970)

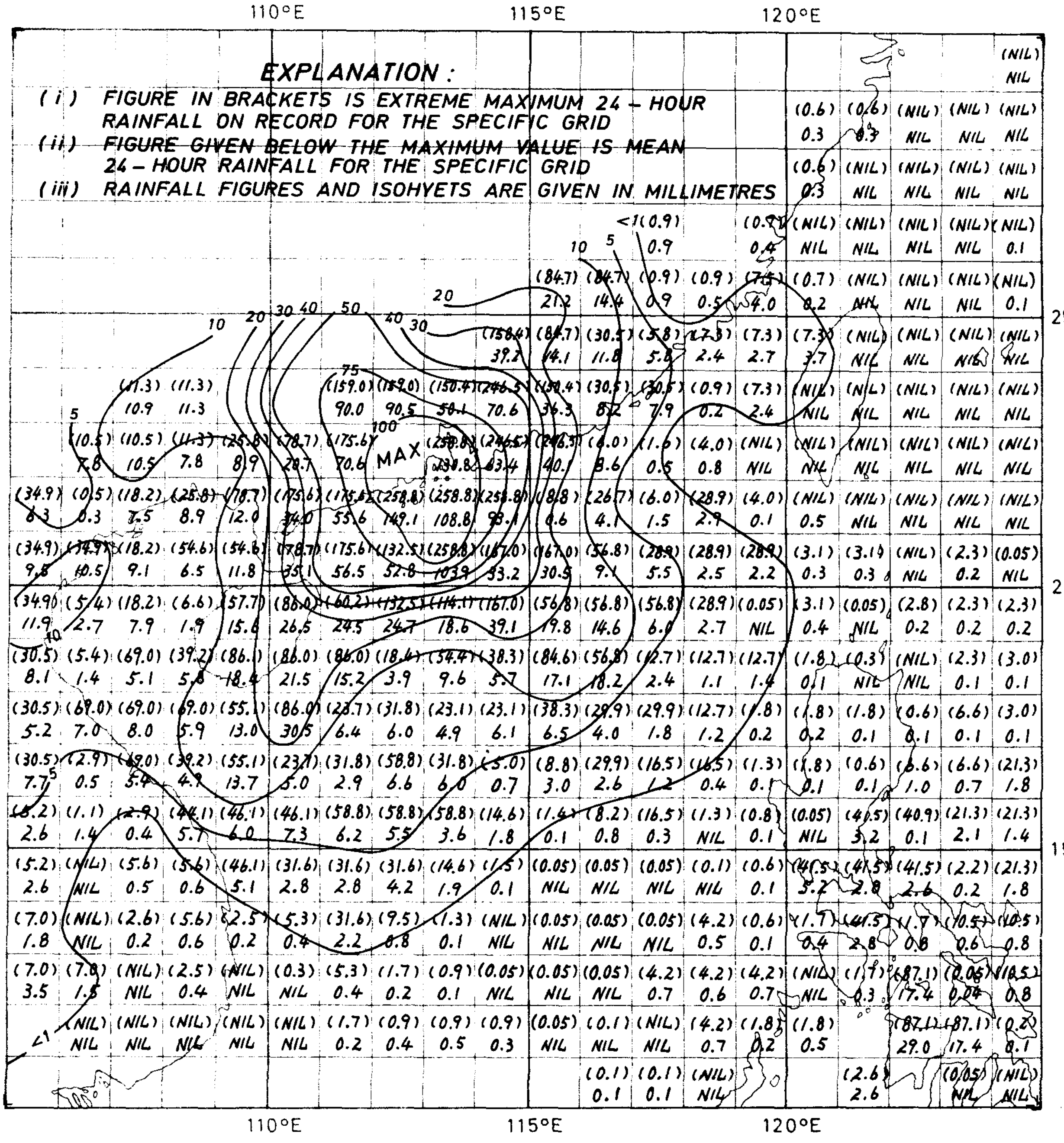


Fig. 14 (f) MEAN 24 - HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN OCTOBER (1884 - 1939, 1947 - 1970)

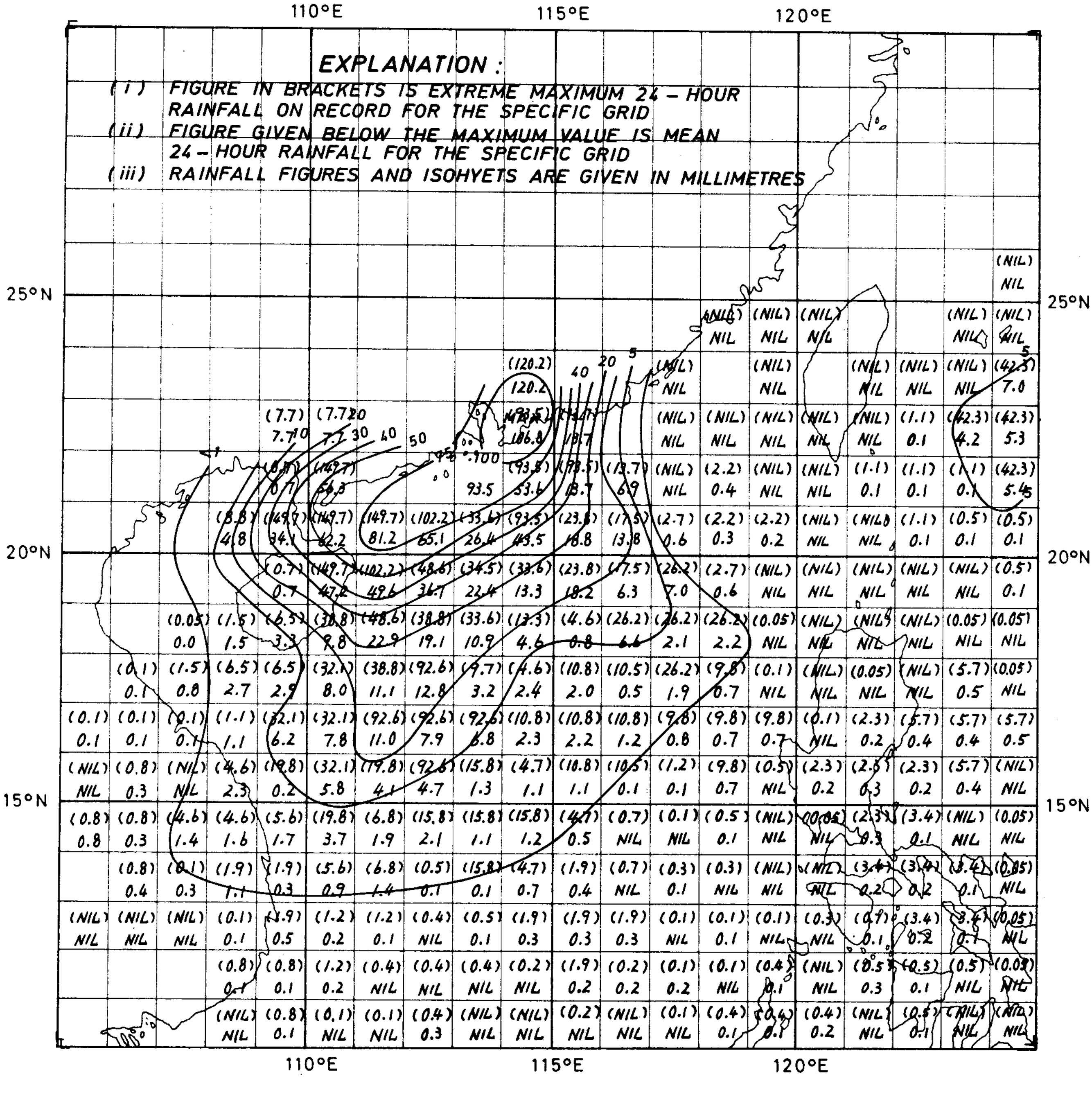


Fig. 14 (g) MEAN 24 - HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN NOVEMBER (1884 - 1939, 1947 - 1970)

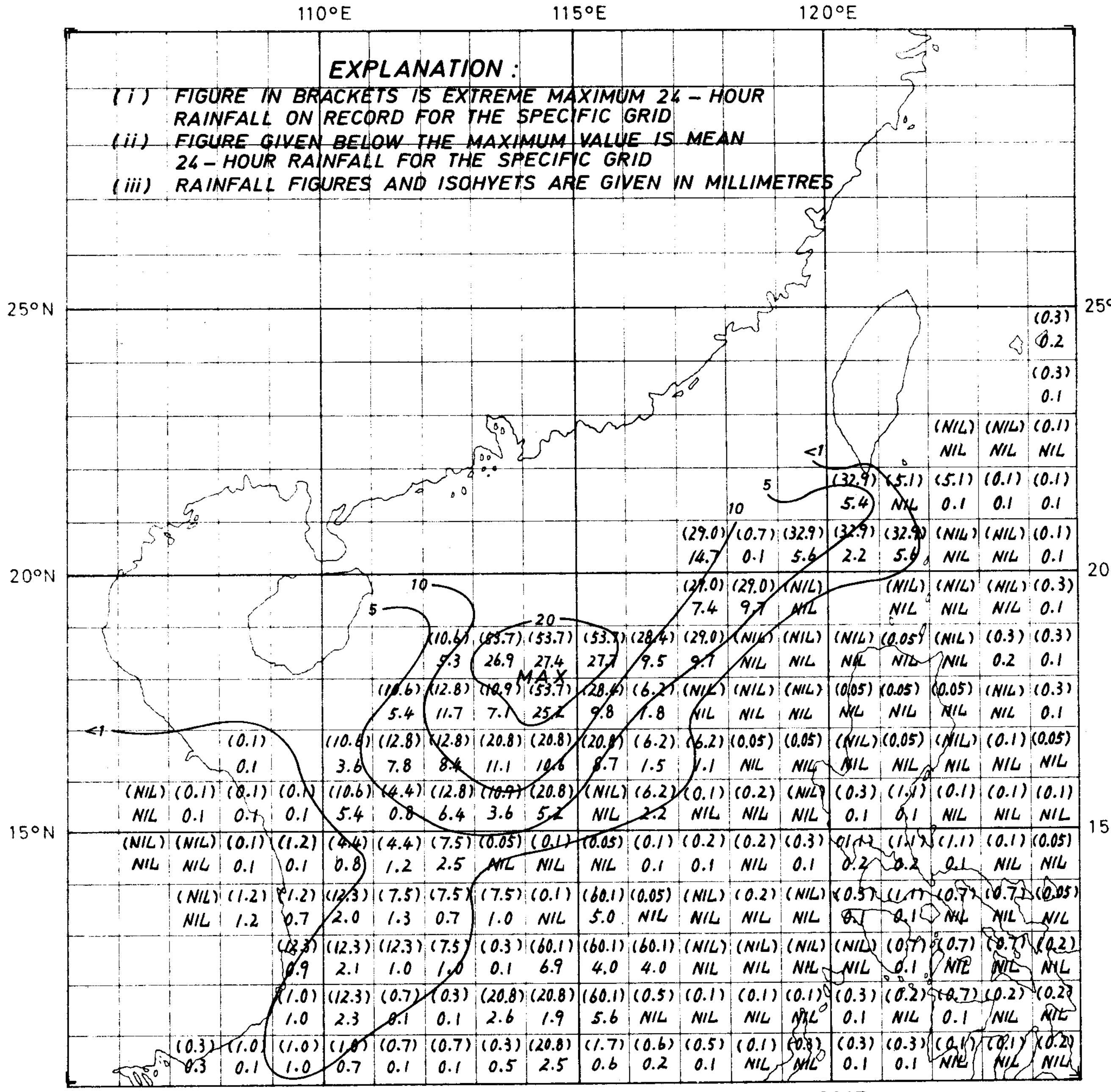


Fig. 14 (h) MEAN 24 - HOUR RAINFALL AT ROYAL OBSERVATORY FOR TROPICAL CYCLONES OCCURRING IN DECEMBER - APRIL (1884-1939, 1947-1970)

Appendix 1. Frequency Distribution of Daily Rainfall Amounts **with** Tropical Cyclones Within 300 Nautical Miles of Hong Kong (1884-1939, 1947-1970)

Month \ Mean No. of days per year \ Daily Rainfall (mm) ≥	0.0	25	50	100	200	300
JAN	NIL	NIL	NIL	NIL	NIL	NIL
FEB	0.1	NIL	NIL	NIL	NIL	NIL
MAR	0.1	0.01	0.01	NIL	NIL	NIL
APR	0.1	NIL	NIL	NIL	NIL	NIL
MAY	1.5	0.2	0.1	0.04	0.03	NIL
JUN	3.3	0.9	0.4	0.1	0.05	NIL
JUL	6.4	1.9	1.0	0.3	0.05	0.01
AUG	7.2	1.8	0.9	0.3	0.1	NIL
SEP	6.4	1.4	0.8	0.3	NIL	0.01
OCT	3.2	0.4	0.3	0.1	0.03	NIL
NOV	1.3	0.1	0.1	NIL	NIL	NIL
DEC	0.3	0.03	NIL	NIL	NIL	NIL
TOTAL PER YEAR	29.9	6.7	3.6	1.1	0.2	0.02
% of Mean Total No. of Rainfall Days Per Year (Due to All Types of Synoptic Situation)	8.2	25.5	33.0	35.5	40.0	28.6

Appendix 2. Frequency Distribution of Daily Rainfall Amounts Due to All Types of Synoptic Situation (including Tropical Cyclones) (1884-1939, 1947-1970)

Month \ Daily Rainfall (mm) ≥ / Mean No. of Days per year	0.0	25	50	100	200	300
JAN	31	0.2	0.05	NIL	NIL	NIL
FEB	28	0.4	0.05	NIL	NIL	NIL
MAR	31	0.5	0.15	NIL	NIL	NIL
APR	30	1.8	0.6	0.1	NIL	NIL
MAY	31	3.1	1.6	0.4	0.1	0.03
JUN	30	5.4	2.2	0.7	0.2	0.03
JUL	31	4.2	1.9	0.5	0.1	0.03
AUG	31	5.0	2.1	0.6	0.05	NIL
SEP	30	4.3	1.5	0.5	0.04	0.01
OCT	31	0.8	0.5	0.1	0.04	NIL
NOV	30	0.5	0.2	0.1	NIL	NIL
DEC	31	0.1	0.04	NIL	NIL	NIL
TOTAL PER YEAR	365	26.3	10.9	3.0	0.5	0.1

Appendix 3(a) The 20 Wettest Tropical Cyclones In Terms of "Total" Tropical Cyclone Rainfall (1884 - 1939; 1947 - 1971)

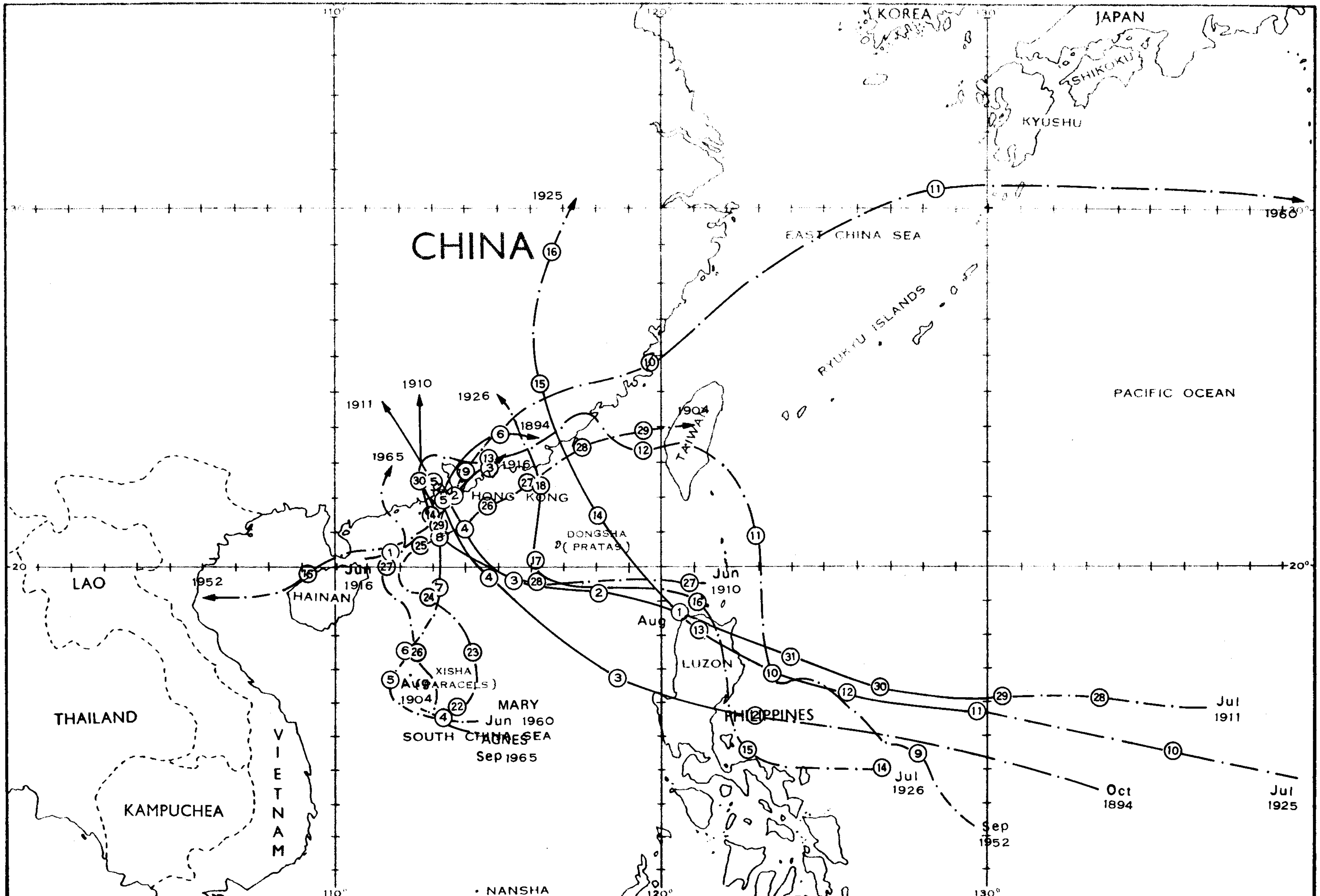
Period "A" when Tropical Cyclone was within 300 nautical miles of Hong Kong	Name of Tropical Cyclone	"Direct" Tropical Cyclone Rainfall during Period "A"	Tropical Cyclone Rainfall during Period "A" and one day after "A"	Total Tropical Cyclone Rainfall during Period "A" & 3 days after "A"
(Year Month Day)		mm	mm	mm
1926 JUL 17-18	-	34.8	568.9	597.4
1916 JUN 1- 3	-	494.7	520.4	559.8
1965 SEP 26-27	AGNES	397.5	413.5	527.4
1904 AUG 23-28	-	443.2	443.2	447.0
1911 AUG 3- 5	-	269.5	437.9	437.9
1894 OCT 4- 6	-	427.1	427.4	427.4
1925 JUL 14-15	-	102.1	140.4	423.2
1960 JUN 7- 9	MARY	419.9	420.1	422.7
1910 JUN 28-30	-	187.0	393.0	419.5
1952 SEP 13-14	-	239.7	281.3	408.1
1923 AUG 26-28	-	99.6	289.9	405.7
1891 MAY 11-12	-	NIL	21.5	353.0
1918 JUN 13-14	-	90.8	168.0	349.4
1971 AUG 15-17	ROSE	340.9	340.9	340.9
1902 AUG 2- 3	-	310.9	311.5	338.4
1917 JUL 14	-	10.9	216.6	332.4
1964 OCT 11-13	DOT	331.1	331.2	331.2
1920 JUL 18-20	-	320.8	326.9	327.7
1909 OCT 19-20	-	320.6	322.9	323.9
1957 SEP 22-23	GLORIA	276.2	281.5	323.2

Appendix 3(b) The 20 Tropical Cyclones In **Terms of** "Direct" Tropical Cyclone Rainfall (1884 - 1939, 1947 - 1971)

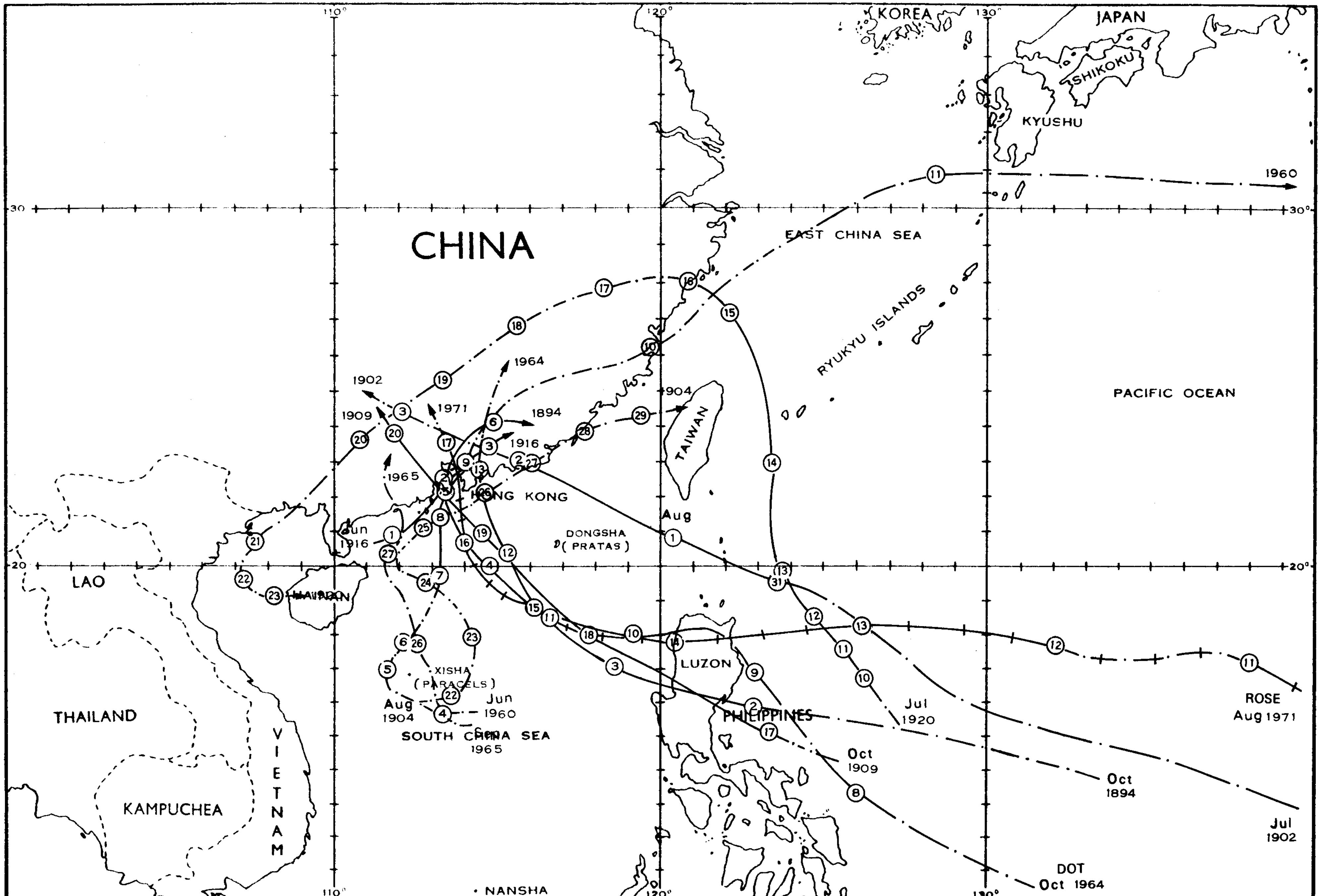
Period "A" when Tropical Cyclone was within 300 nautical miles of H.K.			"Direct" Tropical Cyclone Rainfall during Period "A"	"Indirect" Tropical Cyclone Rainfall during 3-day period "B" after "A"	"Total" Tropical Cyclone Rainfall during Periods "A" and "B"	Rank of Rainfall In terms of "Total" Tropical Cyclone Rainfall
(Year	Month	Day)	mm	mm	mm	
1916	JUN	1- 3	494.7	65.1	559.8	2nd
1904	AUG	23-28	443.2	3.8	447.0	4th
1894	OCT	4- 6	427.1	0.3	427.4	6th
1960	JUN	7- 9	419.9	2.8	422.7	8th
1965	SEP	26-27	397.5	129.9	527.4	3rd
1971	AUG	15-17	340.9	NIL	340.9	14th
1964	OCT	11-13	331.1	0.1	331.2	17th
1920	JUL	18-20	320.8	6.9	327.7	18th
1909	OCT	19-20	320.6	3.3	323.9	19th
1902	AUG	2- 3	310.9	27.5	338.4	15th
1952	JUN	11-15	300.6	5.5	306.1	22nd
1893	OCT	2- 3	289.4	24.9	314.3	21st
1964	MAY	26-28	276.6	24.0	300.6	24th
1957	SEP	22-23	276.2	47.0	323.2	20th
1884	SEP	10-12	275.7	2.1	277.8	29th
1948	JUL	27-28	269.9	6.0	275.9	30th
1911	AUG	3- 5	269.5	168.4	437.9	5th
1962	AUG 31	- SEP 2	262.8	37.6	300.4	25th
1968	AUG	21-22	242.9	9.9	252.8	35th
1952	SEP	13-14	239.7	168.4	408.1	10th

Appendix 3(c) The 20 Tropical Cyclones In Terms of "Indirect" Tropical Cyclone Rainfall (1884 - 1939, 1947 - 1971)

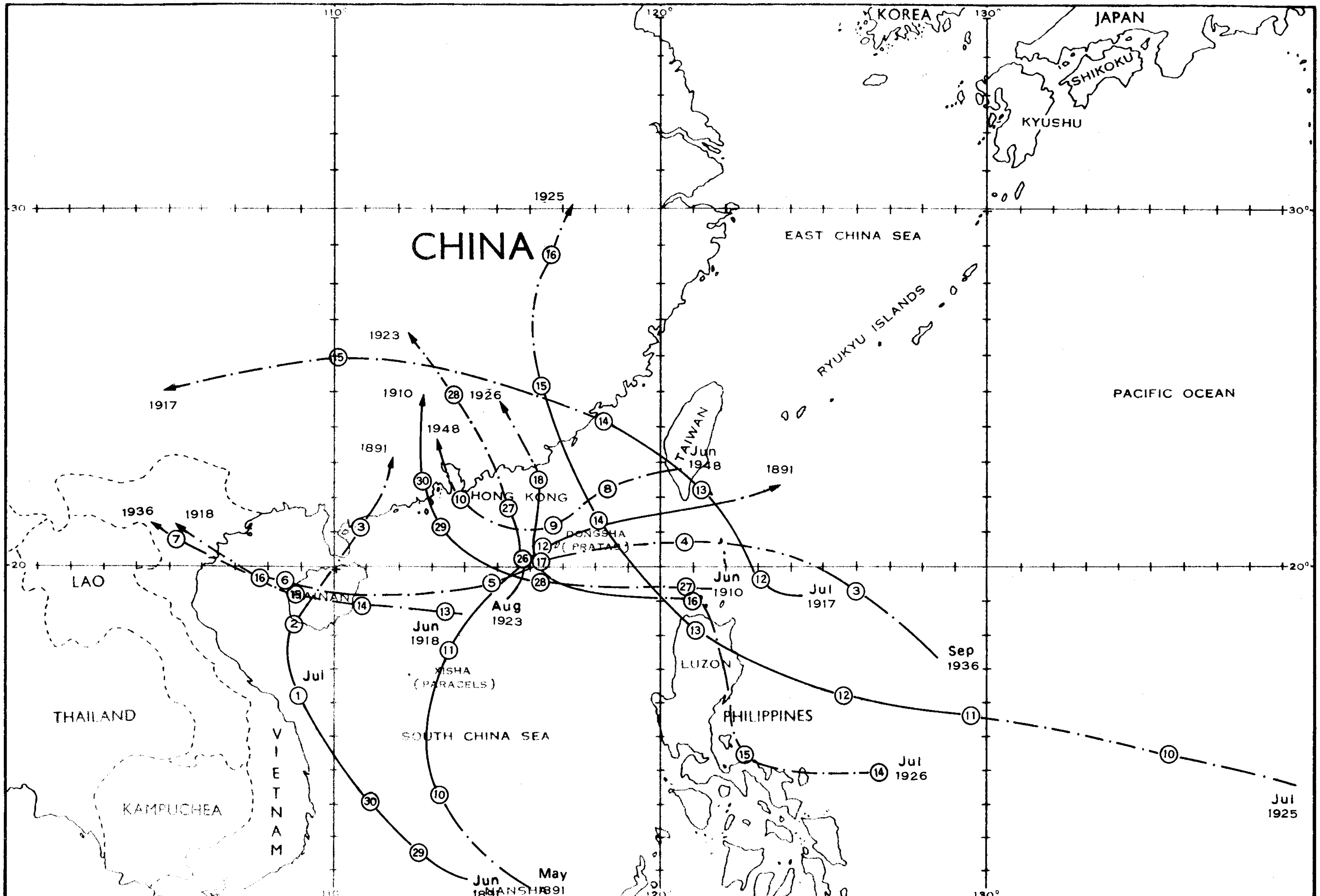
Period "A" when Tropical Cyclone was within 300 nautical miles of H.K.			"Direct" Tropical Cyclone Rainfall during Period "A"	"Indirect" Tropical Cyclone Rainfall during 3-day Period "B" after "A"	"Total" Tropical Cyclone Rainfall during Periods "A" and "B"	Rank of Rainfall In terms of "Total" Tropical Cyclone Rainfall
(Year	Month	Day)	mm	mm	mm	
1926	JUL	17-18	34.8	562.6	597.4	1st
1891	MAY	11-12	NIL	353.0	353.0	12th
1917	JUL	14	10.9	321.5	332.4	16th
1925	JUL	14-15	102.1	321.1	423.2	7th
1923	AUG	26-28	99.6	306.1	405.7	11th
1918	JUN	13-14	90.8	258.6	349.4	13th
1891	JUL	3	21.5	258.5	280.0	28th
1936	SEP	5	26.5	237.7	264.2	33rd
1910	JUN	28-30	187.0	232.5	419.5	9th
1948	JUN	8-10	69.7	221.4	291.1	26th
1947	AUG	29-30	14.9	213.6	228.5	lower than 36th
1960	AUG	25	91.2	201.3	292.5	23rd
1932	JUL	28-29	56.4	187.4	243.8	lower than 36th
1914	JUN	21	2.0	172.9	174.9	lower than 36th
1958	JUL	16	4.2	172.1	176.3	lower than 36th
1918	JUL	29-30	60.3	170.5	230.8	lower than 36th
1930	JUL	14	73.1	169.3	242.4	lower than 36th
1911	AUG	3-5	269.5	168.4	437.9	5th
1952	SEP	13-14	239.7	168.4	408.1	10th
1919	JUL	4	96.3	167.9	264.2	32nd



APPENDIX 4 (a) TRACKS OF THE 10 WETTEST TROPICAL CYCLONES IN TERMS OF "TOTAL" TROPICAL CYCLONE RAINFALL (1884 - 1939, 1947 - 1970)



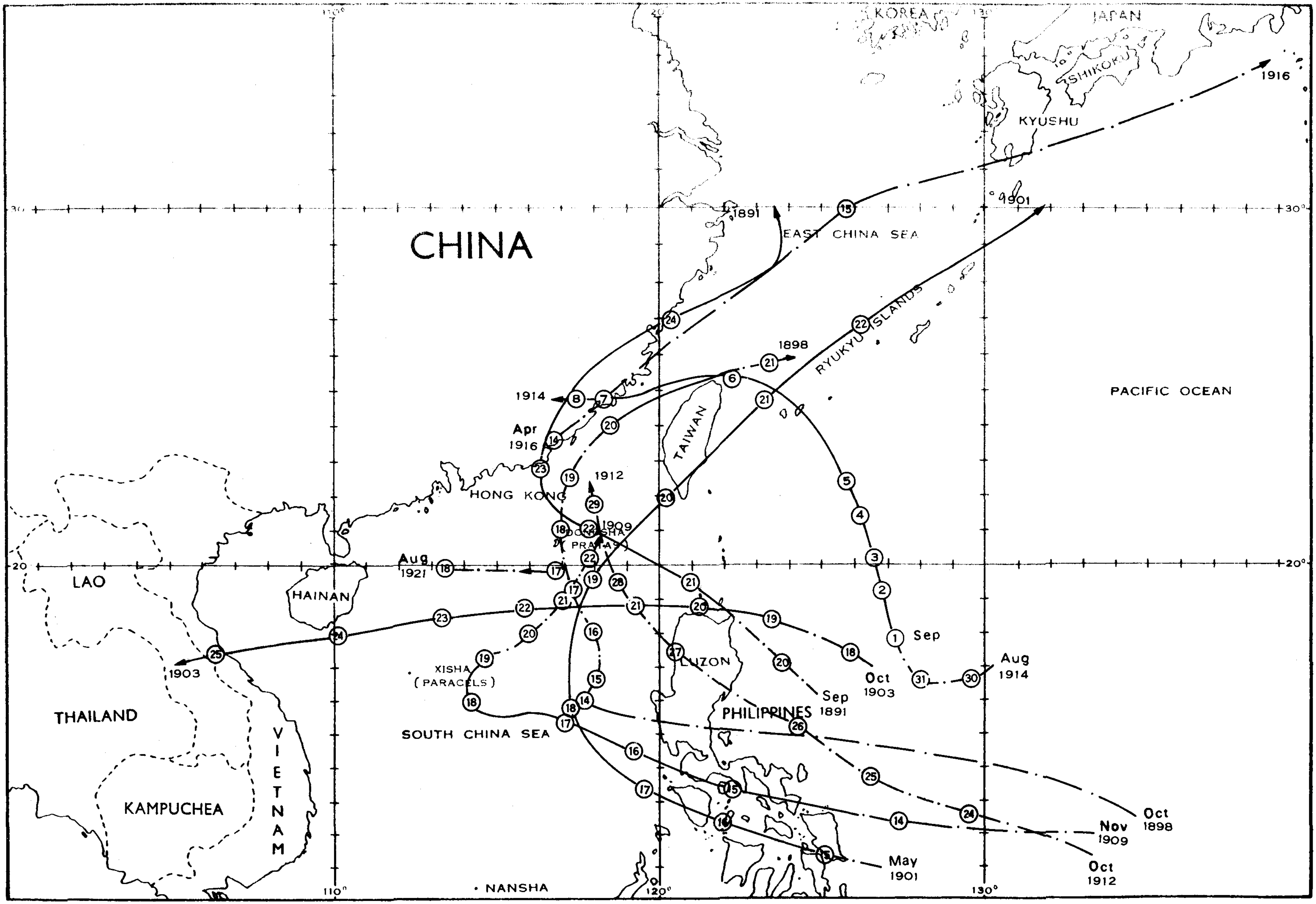
APPENDIX 4 (b) TRACKS OF THE 10 WETTEST TROPICAL CYCLONES IN TERMS OF "DIRECT" TROPICAL CYCLONE RAINFALL (1884 – 1939, 1947 – 1970)



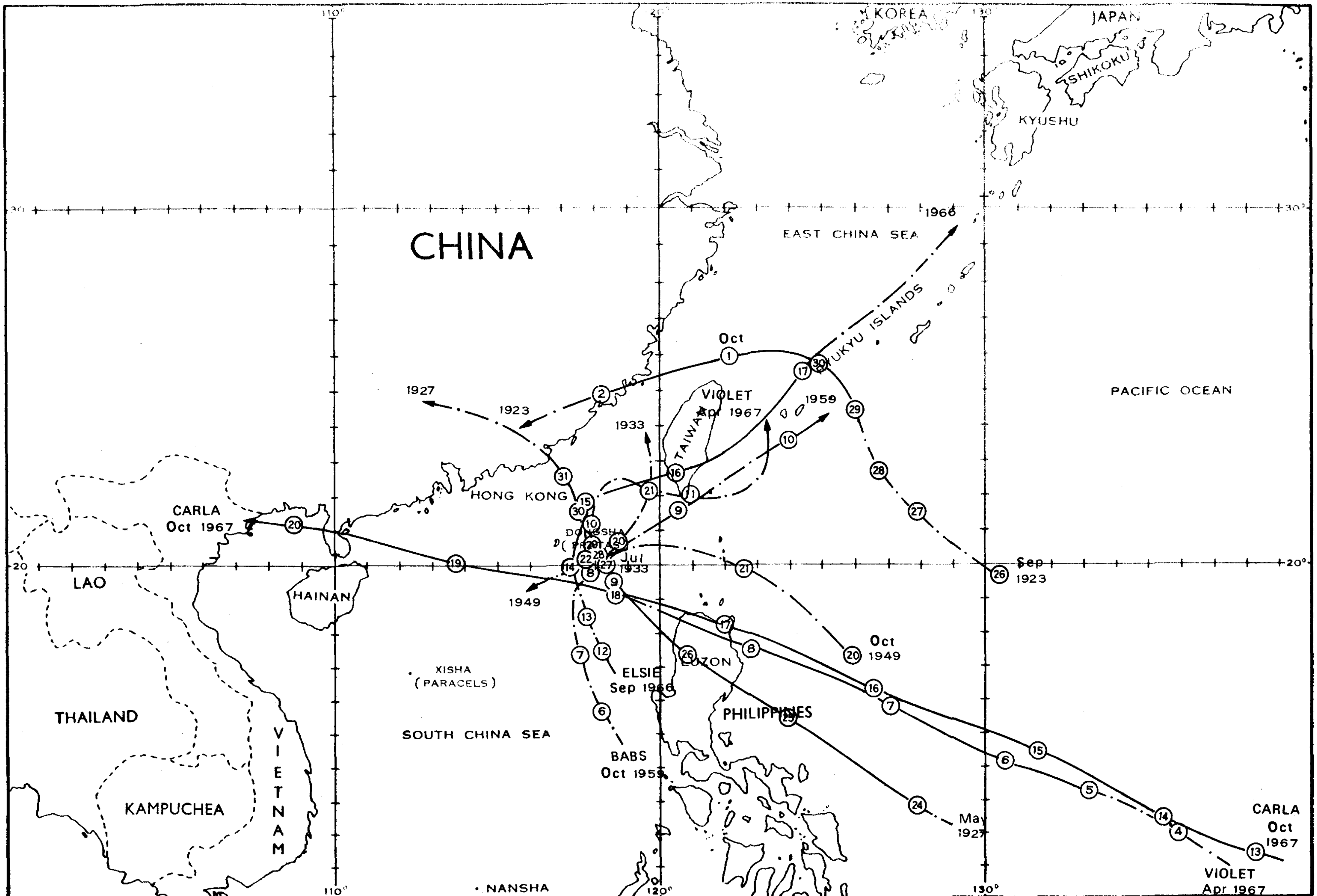
APPENDIX 4 (C) TRACKS OF THE 10 WETTEST TROPICAL CYCLONES IN TERMS OF "INDIRECT" TROPICAL CYCLONE RAINFALL (1884 - 1939, 1947 - 1970)

Appendix 5 The 21 Driest Tropical Cyclones which passed within 300 nautical miles of Hong Kong (1884 - 1939, 1947 - 1970)

Period "A" when Tropical Cyclone was within 300 nautical miles of Hong Kong			Name of Tropical Cyclone	"Direct" Tropical Cyclone Rainfall during Period "A"	"Indirect" Tropical Cyclone Rainfall during 3-day period "B" following "A"	"Total" Tropical Cyclone Rainfall during Periods "A" & "B"	Nearest approach to Hong Kong	
(Year	Month	Day)		mm	mm	mm	Direction	nm
1891	SEP	22-23	-	NIL	NIL	NIL	E	120
1898	OCT	17-20	-	NIL	NIL	NIL	E	160
1901	MAY	19	-	NIL	NIL	NIL	SE	260
1903	OCT	22-23	-	NIL	NIL	NIL	S	220
1909	NOV	21-22	-	NIL	NIL	NIL	SE	240
1912	OCT	29	-	NIL	NIL	NIL	E	210
1914	SEP	7- 8	-	NIL	NIL	NIL	NE	210
1916	APR	14	-	NIL	NIL	NIL	NE	150
1921	AUG	17-18	-	NIL	NIL	NIL	S	150
1923	OCT	2	-	NIL	NIL	NIL	NE	120
1927	MAY	27-31	-	NIL	NIL	NIL	NE	100
1933	JUL	20	-	NIL	NIL	NIL	SE	210
1959	OCT	8	BABS	NIL	NIL	NIL	SE	260
1949	OCT	22	-	NIL	TRACE	TRACE	SE	210
1966	SEP	14-15	ELSIE	TRACE	NIL	TRACE	E	210
1967	APR	10	VIOLET	NIL	TRACE	TRACE	E	210
1967	OCT	19	CARLA	TRACE	TRACE	TRACE	S	150
1949	OCT	4	-	NIL	0.2	0.2	E	160
1954	OCT	9-10	-	TRACE	0.2	0.2	S	240
1894	NOV	19-20	-	NIL	0.3	0.3	E	200
1932	MAY	18	-	NIL	0.3	0.3	SW	210



APPENDIX 6 TRACKS OF THE 17 TROPICAL CYCLONES WITHOUT MEASURABLE RAINFALL RECORDED AT THE ROYAL OBSERVATORY (1884 – 1939, 1947 – 1970)
GRAPH (a)



APPENDIX 6 – GRAPH (b)

Appendix 7(a) Annual Extreme Maximum Daily Rainfall Due to Tropical Cyclones Within 300 Nautical Miles of Hong Kong (1884-1939, 1947-1970)

RANK	YEAR	MONTH	DAY	RAINFALL (mm)	RANK	YEAR	MONTH	DAY	RAINFALL (mm)
1	1926	7	19	534.1	41	1918	6	17	126.9
2	1965	9	27	325.5	42	1957	7	7	126.2
3	1904	8	25	282.7	43	1967	8	21	126.0
4	1891	5	14	264.3	44	1961	9	10	122.0
5	1925	7	17	263.7	45	1919	7	5	121.8
6	1894	10	5	258.8	46	1900	11	10	120.1
7	1964	5	28	248.5	47	1958	9	2	113.4
8	1960	6	9	236.1	48	1895	7	28	107.9
9	1916	6	1	231.9	49	1932	7	30	107.2
10	1911	8	5	218.7	50	1913	9	19	102.9
11	1920	7	19	209.0	51	1939	11	23	102.1
12	1910	7	1	206.0	52	1955	7	10	99.7
13	1917	7	15	205.7	53	1933	9	11	99.3
14	1902	8	2	204.7	54	1888	7	15	98.7
15	1962	9	1	203.0	55	1950	10	5	98.4
16	1957	9	22	199.9	56	1922	9	21	94.0
17	1936	9	7	199.4	57	1954	11	6	93.5
18	1923	8	29	190.3	58	1966	7	14	90.1
19	1970	9	9	188.8	59	1889	10	16	88.1
20	1951	5	13	180.0	60	1924	10	5	86.1
21	1893	10	3	175.5	61	1903	9	12	83.8
22	1949	9	8	168.7	62	1929	7	12	81.0
23	1968	8	21	165.1	63	1934	8	3	81.0
24	1948	7	27	162.5	64	1969	7	28	78.6
25	1909	10	19	161.8	65	1912	9	20	74.7
26	1952	6	13	155.9	66	1931	8	1	68.8
27	1921	9	3	153.9	67	1938	10	4	63.0
28	1953	9	27	153.6	68	1963	7	22	61.5
29	1937	9	2	150.6	69	1908	7	28	60.5
30	1897	11	17	149.2	70	1886	10	12	56.9
31	1887	9	17	148.7	71	1892	6	30	52.3
32	1903	7	24	148.1	72	1885	8	17	43.1
33	1927	8	20	143.5	73	1905	8	30	42.7
34	1884	9	10	141.9	74	1928	8	13	34.8
35	1907	9	15	140.5	75	1898	8	4	33.8
36	1906	9	29	133.7	76	1915	8	2	32.0
37	1914	6	22	133.3	77	1956	6	5	29.7
38	1899	8	23	132.6	78	1890	6	30	26.3
39	1896	10	6	132.5	79	1935	8	7	22.5
40	1947	8	31	129.2	80	1901	-	-	-

Appendix 7(b) Annual Extreme Maximum Daily Non-Tropical Cyclone Rainfall (1884-1939, 1947-1970)

RANK	YEAR	MONTH	DAY	RAINFALL (mm)	RANK	YEAR	MONTH	DAY	RAINFALL (mm)
1	1889	5	30	520.6	41	1907	6	22	134.0
2	1966	6	12	382.6	42	1914	6	22	133.5
3	1886	7	15	342.3	43	1904	6	29	131.8
4	1885	6	12	320.9	44	1935	6	15	130.0
5	1923	10	31	292.2	45	1967	4	2	128.1
6	1892	6	16	275.4	46	1915	10	19	124.1
7	1959	6	15	270.3	47	1893	5	29	122.4
8	1970	5	13	265.1	48	1956	8	6	118.1
9	1957	5	22	246.2	49	1962	5	26	114.2
10	1934	6	22	230.1	50	1961	8	31	108.5
11	1969	8	11	220.8	51	1901	4	7	107.5
12	1903	6	28	215.9	52	1917	7	25	104.4
13	1888	6	26	215.2	53	1928	5	29	104.2
14	1900	6	15	214.7	54	1958	7	28	103.5
15	1902	8	2	204.7	55	1960	9	10	103.2
16	1930	9	7	202.2	56	1950	5	20	101.5
17	1905	6	1	202.0	57	1913	3	17	96.1
18	1968	6	13	200.0	58	1899	9	14	96.0
19	1925	6	15	191.8	59	1938	5	20	95.7
20	1918	8	3	187.8	60	1884	7	21	94.2
21	1927	5	23	184.3	61	1916	5	31	93.5
22	1929	8	16	181.8	62	1965	4	28	92.3
23	1908	7	23	177.8	63	1931	12	9	91.1
24	1947	7	1	172.7	64	1906	9	26	89.5
25	1924	6	23	167.7	65	1898	6	7	89.0
26	1910	6	2	166.4	66	1937	5	18	85.6
27	1949	6	25	164.1	67	1887	4	12	81.4
28	1894	5	18	157.0	68	1952	8	9	80.7
29	1920	6	12	155.9	69	1911	8	18	75.6
30	1912	8	15	155.7	70	1922	6	21	74.9
31	1932	8	4	155.3	71	1953	6	6	73.8
32	1897	6	28	153.0	72	1964	8	16	72.7
33	1921	5	24	150.2	73	1963	7	19	71.9
34	1948	9	22	149.3	74	1919	7	28	71.7
35	1890	7	19	147.8	75	1954	7	8	67.6
36	1939	4	20	145.2	76	1896	9	16	66.9
37	1926	9	21	142.5	77	1936	7	19	63.3
38	1891	6	24	140.0	78	1909	5	22	57.4
39	1951	6	7	135.5	79	1933	6	2	52.5
40	1955	8	18	135.3	80	1895	4	24	47.4

Appendix 8(a) Annual Extreme Maximum Hourly Rainfall Due to Tropical Cyclones Within 300 Nautical Miles of Hong Kong (1884-1939, 1947-1970)

RANK	YEAR	MONTH	DAY	HOUR (H.K.St. TIME)	RAINFALL (mm)	RANK	YEAR	MONTH	DAY	HOUR (H.K.St. TIME)	RAINFALL (mm)
1	1926	9	27	06	100.7	41	1934	6	26	17	32.8
2	1925	7	17	07	73.1	42	1960	6	9	09	32.6
3	1936	8	2	07	71.1	43	1968	8	21	16	32.0
4	1970	8	2	19	65.6	44	1906	9	18	10	31.7
5	1910	7	1	02	64.8	45	1900	11	10	05	31.5
6	1964	10	13	05	60.5	46	1955	7	10	16	30.6
7	1917	7	15	02	60.1	47	1966	7	13	24	30.1
8	1911	8	5	23	59.7	48	1951	5	13	14	29.7
9	1962	9	1	08	55.1	49	1892	9	19	22	29.1
10	1916	6	2	01	54.6	50	1920	7	19	10	28.5
11	1937	9	2	05	54.6	51	1888	7	15	24	28.3
12	1918	8	2	24	53.3	52	1959	7	9	15	27.4
13	1884	6	30	06	51.6	53	1886	10	12	20	27.3
14	1961	7	1	20	48.8	54	1933	7	30	06	26.7
15	1965	9	27	02	47.4	55	1907	9	15	19	26.0
16	1909	9	21	16	45.7	56	1903	9	12	17	26.0
17	1914	6	22	04	45.5	57	1896	7	29	05	25.1
18	1899	8	7	24	45.2	58	1938	10	4	15	24.9
19	1897	9	18	07	43.7	59	1932	6	2	12	24.6
20	1891	7	4	10	42.2	60	1919	6	14	02	24.0
21	1893	10	3	22	41.9	61	1967	8	22	01	23.6
22	1904	8	25	07	41.9	62	1889	8	4	22	23.5
23	1895	7	28	18	41.4	63	1928	8	13	20	23.4
24	1927	8	30	02	41.1	64	1949	11	15	15	23.3
25	1923	8	29	09	40.3	65	1924	6	5	10	22.9
26	1952	9	14	06	40.2	66	1929	7	12	09	22.9
27	1957	7	17	09	38.3	67	1930	7	25	09	22.1
28	1939	11	23	11	38.0	68	1905	7	4	24	21.8
29	1913	7	31	10	36.2	69	1931	8	1	15	20.8
30	1894	10	5	18	35.6	70	1922	9	21	02	20.3
31	1948	6	12	01	35.3	71	1898	8	14	09	19.8
32	1887	9	17	16	35.3	72	1969	8	30	22	19.6
33	1912	7	25	04	34.9	73	1908	10	11	20	18.9
34	1902	8	2	21	34.3	74	1935	8	29	04	16.9
35	1953	8	14	08	33.9	75	1956	6	5	20	14.3
36	1904	8	11	06	33.7	76	1954	5	12	09	13.9
37	1958	7	26	09	33.7	77	1885	8	17	08	12.6
38	1947	8	31	18	33.4	78	1915	6	30	08	12.1
39	1921	8	8	01	33.3	79	1890	6	30	09	8.8
40	1963	8	29	17	33.1	80	1901	-	-	-	-

Appendix 3(b) Annual Extreme Maximum Hourly Non-Tropical Cyclone Rainfall (1884-1939, 1947-1970)

RANK	YEAR	MONTH	DAY	HOUR (H.K.St. Time)	RAINFALL (mm)	RANK	YEAR	MONTH	DAY	HOUR (H.K. St. Time)	RAINFALL (mm)
1	1966	6	12	07	108.2	41	1890	5	21	11	49.5
2	1968	6	13	03	100.0	42	1906	9	26	23	49.5
3	1886	7	15	15	88.4	43	1901	8	5	03	48.3
4	1889	5	30	04	86.4	44	1950	5	20	04	48.2
5	1947	7	1	11	85.0	45	1960	7	28	08	48.0
6	1948	9	22	14	84.0	46	1936	5	18	23	46.7
7	1921	5	31	14	82.6	47	1896	6	23	01	46.6
8	1925	6	15	23	80.3	48	1893	4	28	20	46.4
9	1970	5	13	10	75.6	49	1962	5	26	08	45.8
10	1900	6	15	09	72.5	50	1914	9	28	02	45.7
11	1923	10	31	02	71.6	51	1912	6	21	09	45.2
12	1905	6	1	09	71.7	52	1891	6	24	10	45.1
13	1888	5	19	13	69.6	53	1884	7	21	08	44.7
14	1935	6	15	05	69.6	54	1924	5	22	13	44.2
15	1939	5	22	06	69.6	55	1928	6	1	13	43.2
16	1929	8	16	04	69.3	56	1902	11	16	01	42.9
17	1967	6	2	22	69.1	57	1949	6	25	04	42.0
18	1957	6	17	09	68.8	58	1922	8	28	20	41.3
19	1953	6	6	01	67.8	59	1899	9	14	03	40.6
20	1955	4	1	18	67.6	60	1908	7	23	10	39.8
21	1959	6	14	05	67.3	61	1904	6	29	16	39.0
22	1958	5	23	05	66.6	62	1894	5	20	09	38.1
23	1897	6	9	03	64.8	63	1956	8	8	16	38.0
24	1931	4	19	21	64.8	64	1938	7	9	17	37.3
25	1932	6	14	12	63.0	65	1913	6	7	15	37.1
26	1885	4	20	11	61.5	66	1916	5	31	04	37.1
27	1918	9	21	02	61.5	67	1954	4	8	19	36.7
28	1930	8	21	09	60.1	68	1920	9	12	21	36.4
29	1965	4	28	19	58.5	69	1952	9	23	01	34.4
30	1969	8	11	12	58.1	70	1919	10	1	06	34.3
31	1903	6	28	08	55.9	71	1937	7	26	23	33.8
32	1892	6	16	07	54.6	72	1887	7	5	09	33.5
33	1934	6	22	05	54.6	73	1917	4	12	16	33.0
34	1951	6	29	06	54.6	74	1895	4	24	16	32.1
35	1915	10	19	09	54.1	75	1963	7	19	13	32.0
36	1927	5	1	13	53.3	76	1911	5	20	10	31.4
37	1961	8	17	13	52.3	77	1933	9	28	24	30.2
38	1910	6	2	24	50.3	78	1964	8	16	14	29.5
39	1907	5	7	06	49.8	79	1898	10	3	24	27.2
40	1926	4	28	05	49.8	80	1909	8	23	06	17.9