RAIN FROM TROPICAL CYCLONES AND TROUGH-TYPE SYSTEMS

by Mr. P. C. Chin

1. Introduction

In the atmosphere, rainstorms of various sizes can be found, and the related phenomenon observed is determined by the scale of observations. However, in general, all these disturbances correspond to the following two basic types of atmospheric instability:

(a) gravitational instability, leading to convection in which the vertical and horizontal motions are comparable and on the same scale as that of the depth of the troposphere;

(b) baroclinic instability, producing disturbances in which the motion is nearly horizontal and the vertical velocities are two orders of magnitude smaller than the horizontal velocities. The motion is also markedly influenced by the earth's rotation, and the horizontal dimension of the disturbances is of the order of 1000 km.

These rainstorms are modified, often strongly, by disturbances due to topographical peculiarities whose scale is dependent on the responsible ground feature. An example is the intensification of rainfall over and near high ground by mountain waves. Sea breezes tend to localize convective clouds in a narrow belt inland and differences in temperature between land and sea similarly modify the intensity of convective clouds on a relatively large scale.

Fundamental rain-forming processes cannot always be separated in many rainstorms. Thus, it is common to observe convective instability in frontal depressions, either within the main cloud mass or along a front, while persistent, widespread rain may result from the spreading of thunderclouds, suggesting that only the lifting process is at work.

2. Types of synoptic disturbances

Heavy rainfall over the various regions in Southeast Asia is generally associated with the following types of disturbances:

(a) tropical cyclones

(b) monsoon depressions and cyclonic vortices

(c) quasi-stationary or slow-moving fronts, troughs and convergence zones

(d) easterly or westerly moving troughs or vortices in the upper levels.

The primary feature of these disturbances is a relative extensive area of convergence where local heavy rain, which may be in the form of thundery showers, is embedded in a larger area of "background" rainfall. It is generally known that rainfall is usually enhanced by the simultaneous presence of surface and upper-air disturbances. Studies in Hong Kong reveal that extreme rains are mostly due to intense convective cells embedded in troughs and in tropical cyclones, so that both types form the controlling systems for this region.

3. Troughs and frontal systems

Troughs and frontal systems are generally zones of marked and widespread low-level convergence, and usually provide sufficient lifting to bring about an overturning of moist tropical air, resulting in the occurrence of heavy rainfall. A primary factor of importance in producing significantly large amounts of rainfall is the presence of a south to southwesterly flow at the lower levels (normally below 3,000 m), which maintains a generous supply of moist air from the warm sea.

Fronts over the subtropical regions in the Far East are generally characterized by gently sloping surfaces, and the precipitation area is therefore more extensive than that in temperate-latitude systems. Furthermore, the rain associated with quasi-stationary or slow-moving fronts is more persistent than in the case with tropical cyclones. When convective activity is absent in these systems, the rainfall will become more uniform as the orographic effect is substantially reduced.

4. Climatology of the monsoon trough (the Mei-yu or Baiu trough)

The characteristic properties of the monsoon trough over Southeast Asia have been studied extensively by many workers (Yin, 1949; Dao et al, 1958; Ramanathan, 1960; Kao et al, 1962; Mizukoshi, 1964; and Yoshino, 1965, 1966). The general northward movement of the system during the summer months can be seen from the distribution of the occurrence of fronts shown in Figures 1a and 1b. This is in phase with the northward displacement of the pentad rainfall belt shown in Figure 2. However, such systematic movements cannot be found on a day-to-day basis, and the trough may linger for an exceptionally long period over a particular locality. As an example, the severe rainstorms which occurred on 12 June 1966 in Hong Kong and gave rise to several rainfall records were in fact associated with an almost stationary trough along the South China coast (Chen, 1968).

5. Distribution of rainfall in a trough

Although the rainfall in a trough is usually widespread, it is highly variable and no definite patterns can be obtained. Figure 3 shows the frequency of occurrence of troughs at various distances from Hong Kong and the amount of rain recorded at the Royal Observatory. The mean values of observed rainfall in Hong Kong associated with troughs at different distances away from the storm are shown in Figure 4. In view of the high variability of rainfall, these figures only serve to provide a crude climatological estimate of "trough rainfall", and the accurate prediction of heavy rain will depend on (a) the successful identification of favourable conditions, such as the presence of low-level convergence and cyclonic vorticity and upper-level divergence and anticyclonic vorticity, lack of strong wind shear, an abundant supply of moisture, and a high degree of instability or (b) the detection of disturbances on a smaller scale by means of radar and other elaborate techniques.

6. Tropical cyclones

Tropical cyclones combine an intense mechanism of low-level convergent flow with high moisture supply, and are therefore potential storms for producing heavy rainfall. The average annual number of storms occurring over the various regions and the percentage of these to the global total are shown in Table 1. The seasonal variation of tropical cyclones (with maximum sustained winds of 35 knots or greater) over the northern and southern hemispheres is shown in Figures 5a and 5b. It is seen that these storms are essentially disturbances of the summer months. The average percentage contribution of rainfall by tropical cyclones for each year is about 10% for South Korea, 7-25% for Japan, 66-68% for Luzon, 24% for Hong Kong and 13-22% for Taiwan. The amount of rain produced by tropical cyclones is also highly variable, and depends on the size of the storm, its track and speed of movement and the flow pattern at the surface and aloft. However, most findings (Schoner and Molansky, 1956, U.S. Weather Bureau, 1963, and Chin, 1965) reveal that there is little correlation between rainfall intensity and wind strength. Ramage (1959) and Gray (1967) have advocated the importance of vertical shear in the development of tropical storms, and a typical pattern suggested by Gray for the intensification of these disturbances, is reproduced in Figure 6. He also showed that cumulus convection is most intense where the tropospheric vertical wind shear is smallest.

7. Areal distribution of rainfall

Because of the difficulty in obtaining rainfall data over the oceans, relatively few studies have been made in determining the areal rainfall distribution in tropical cyclones. Miller (1958) has tabulated the mean areal rainfall for 1° square grids based

Table 1

Areas where tropical storms develop[1] (After Gray)

Area No.	Area Location	Average Percentage of Global Total	Average Number of Tropical Storms Per Year
I	NE Pacific	16 (?)	10 (?)
II	NW Pacific	36	22
III	Bay of Bengal	10	6
IV	Arabian Sea	3	2
V	South Indian Ocean	10	6
VI	Off NW Australian Coast	3	2
VII	South Pacific	11	7
VIII	NW Atlantic (including W. Caribbean and Gulf of Mexico)	11	7
	Total	100	62

[1] Tropical storms are defined as a warm-core vortex circulation with sustained maximum winds of at least 40 mph.

on 16 hurricanes passing over or near Florida, and the distribution as shown in Figure 7 is considered as the most accurate representation that can be obtained around a hurricane. However, the effect of change in the frictional drag between land and sea has not been evaluated. Similar analyses were carried out by Liu and Tung (1958),

but the patterns obtained were all associated with rapidly filling typhoons over land. Miller (1963) has also computed a composite isohyetal pattern for Hurricane Donna of 1960 which moved through a region of dense observational network and had a distribution very similar to the mean pattern obtained in his earlier study. The rainfall distribution observed in Japan associated with typhoons has also been examined on a geographical basis by Sekiguti (1965).

For the purpose of preparing flash-flood warnings or determining the probable maximum precipitation for an area, an estimate of the radial distribution of rain from the storm centre is required. This may be obtained by actual observations by means of radar or by the use of storm models. An example of a hurricane model developed by the Hydrologic Studies Section of the U.S. Weather Bureau based on the findings of many workers is presented in Figure 8. The variation of rainfall with distance In Hong Kong, a 'climatological' model has been constructed from over 100 tropical cyclones for use in the South China coastal region. This model as shown in Figure 10 is derived from observations of rainfall recorded in Hong Kong when tropical storms or typhoons were centred at the various distances away in the area. The marked decrease of rain with distance in the southern side of the storm (as seen by the tight isohyetal gradient) is probably due to its rapid filling over land.

8. Movement of tropical cyclones

Since the variation of rainfall at a particular locality depends greatly on the track of a tropical cyclone, prediction of its movement is therefore of paramount importance in preparing quantitative forecasts. The most common procedures that have been widely used and tested in various countries during recent years are (a) climatological forecasts, (b) persistence forecasts, (c) synoptic-climatological techniques and (d) numerical prediction. A comprehensive survey of these methods has been given by Gentry (1963) and verification tests of several objective techniques used in Hong Kong for the western Pacific and South China Sea area were made by Chin (1964, 1968). It appears that despite the rapid advance in the development of dynamic models in recent years, the results produced by the numerical technique have not been proved to be significantly better than those prepared by simple climatological techniques modified by synoptic judgement. The ½ (persistence + climatology) method as described by Bell (1962) has proved to be particularly useful. Another simple and well-tried technique in this region is that due to Veigas-Miller, which is based on the surface pressure readings at certain fixed points with respect to the tropical cyclone centre. The advantage of this method is that it does not require any upper-air observations which are so sparsely distributed in this region.

9. An example of preparing quantitative rainfall forecasts

A very comprehensive study on the prediction of rainfall amounts associated with tropical cyclones has been made by Gilman et al. (1960) and the techniques proposed are based on the computation of dynamic trajectories and other meteorological parameters. Successful application of these techniques in the western Pacific and South China Sea area would probably require a much more dense network of observation stations than is at present available.

In Hong Kong, forecasts of rainfall for the whole territory have been made by use of the two tropical cyclone models described above. The procedure requires the preparation of a forecast track of the storm, and the total rainfall expected for a period is obtained by the integration of the rate of rainfall between successive isolines over various time intervals. The forecast prepared in this way only represents a value derived from a "mean storm" and adjustments are necessary using the radar atlas and synoptic judgement.

In the hurricane model developed by U.S.W.B., separate computations of covergence and orographic rainfall have to be made, and the final forecast is obtained by a combination of the two contributions. Appropriate corrections may be applied if the actual parameters observed depart significantly from those used in the model.

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Figure 1 a

Distribution of the frequency of occurrence (%) of fronts at the sea level and at the 850 mb level. (After Yoshino)

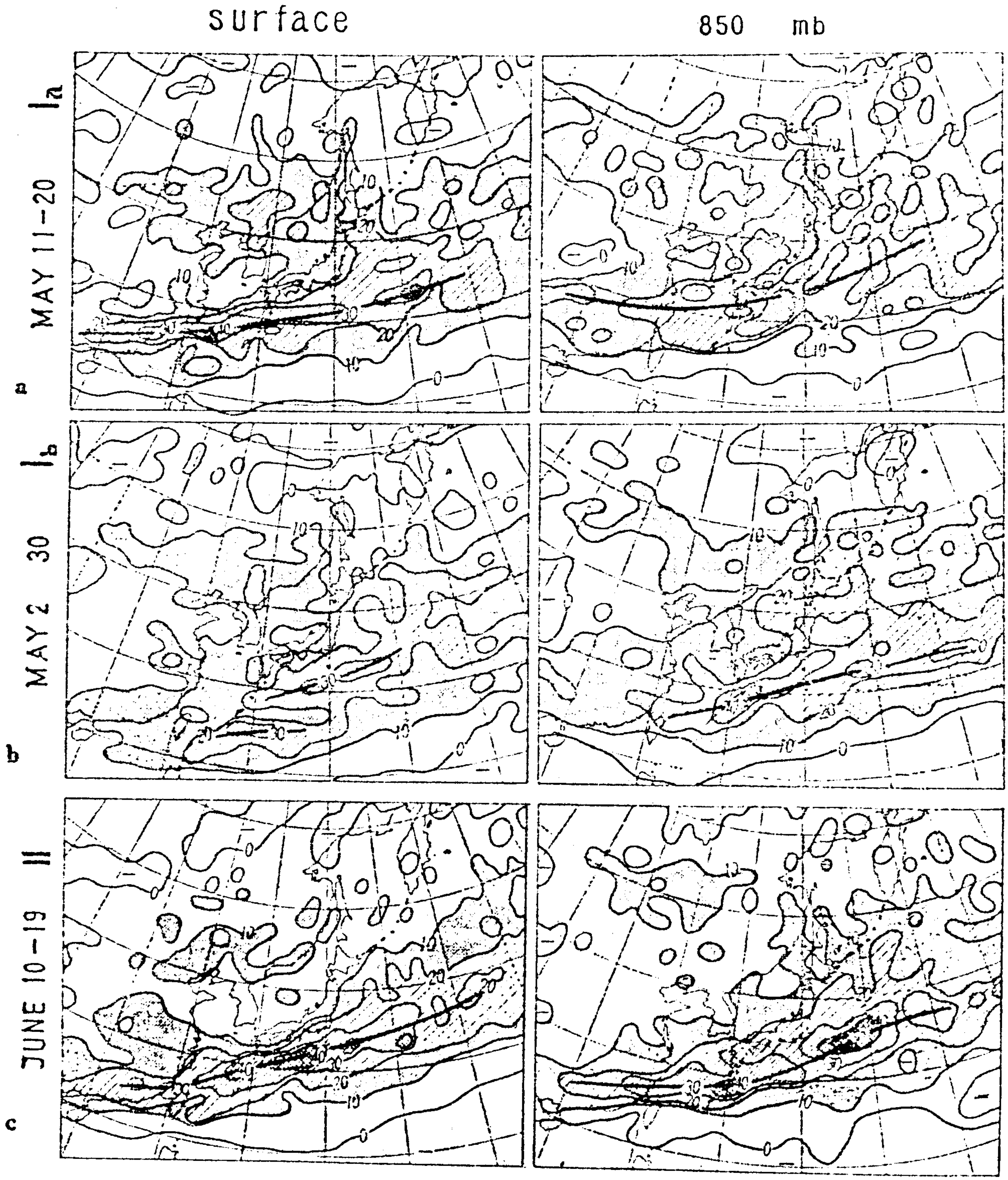


Figure 1 b

Distribution of the frequency of occurrence (%) of fronts at the sea level and at the 850 mb level. (After Yoshino)

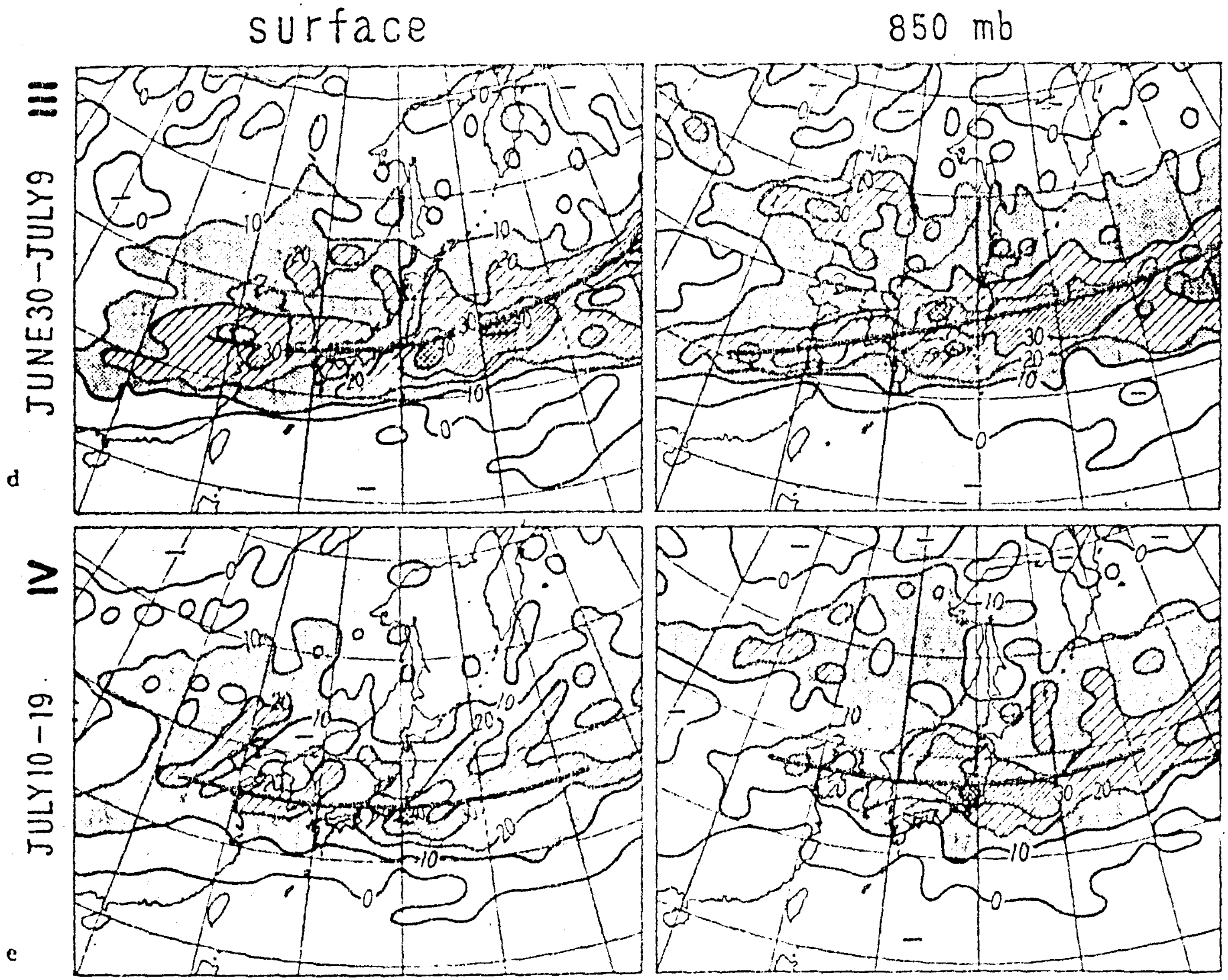
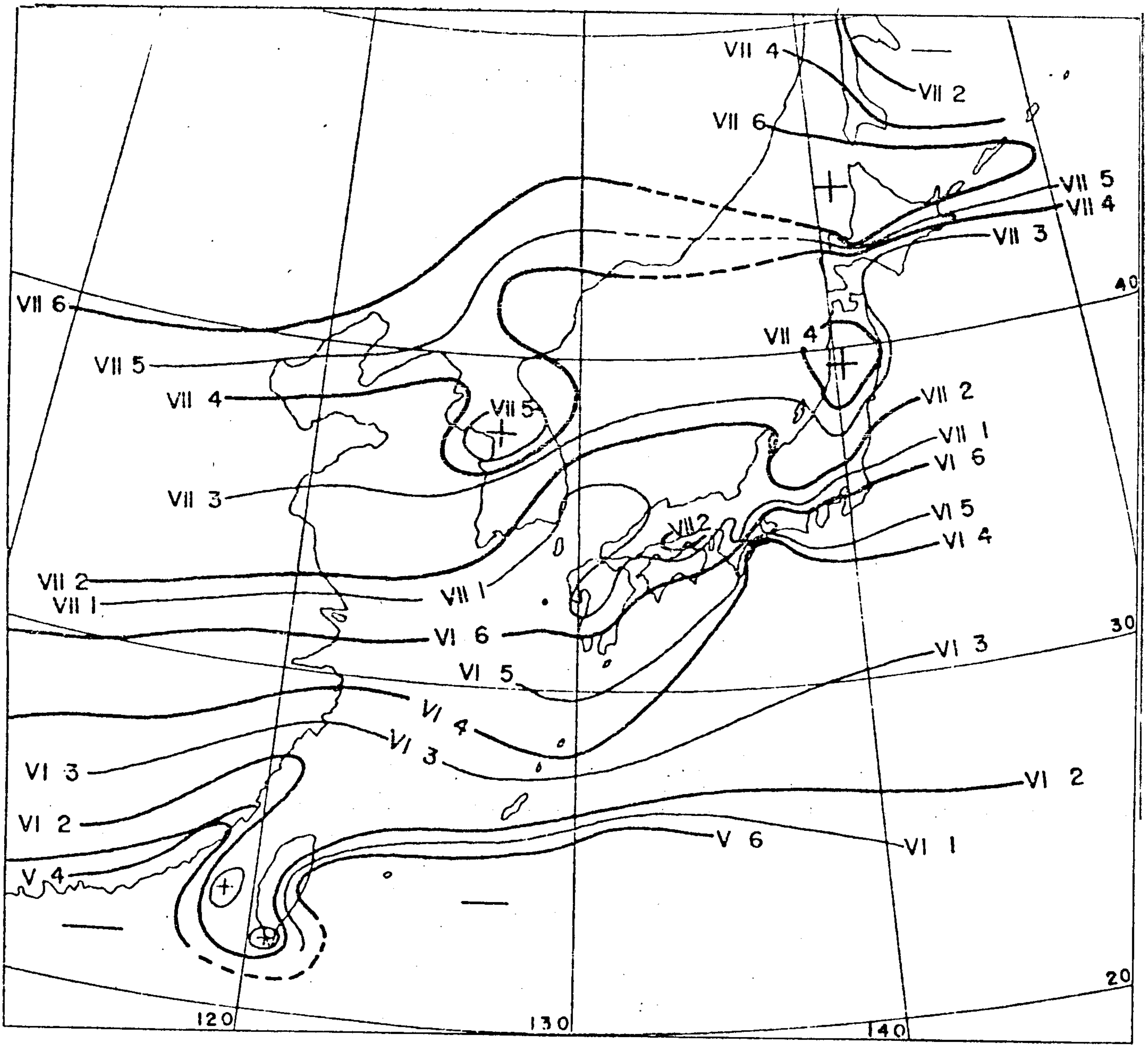


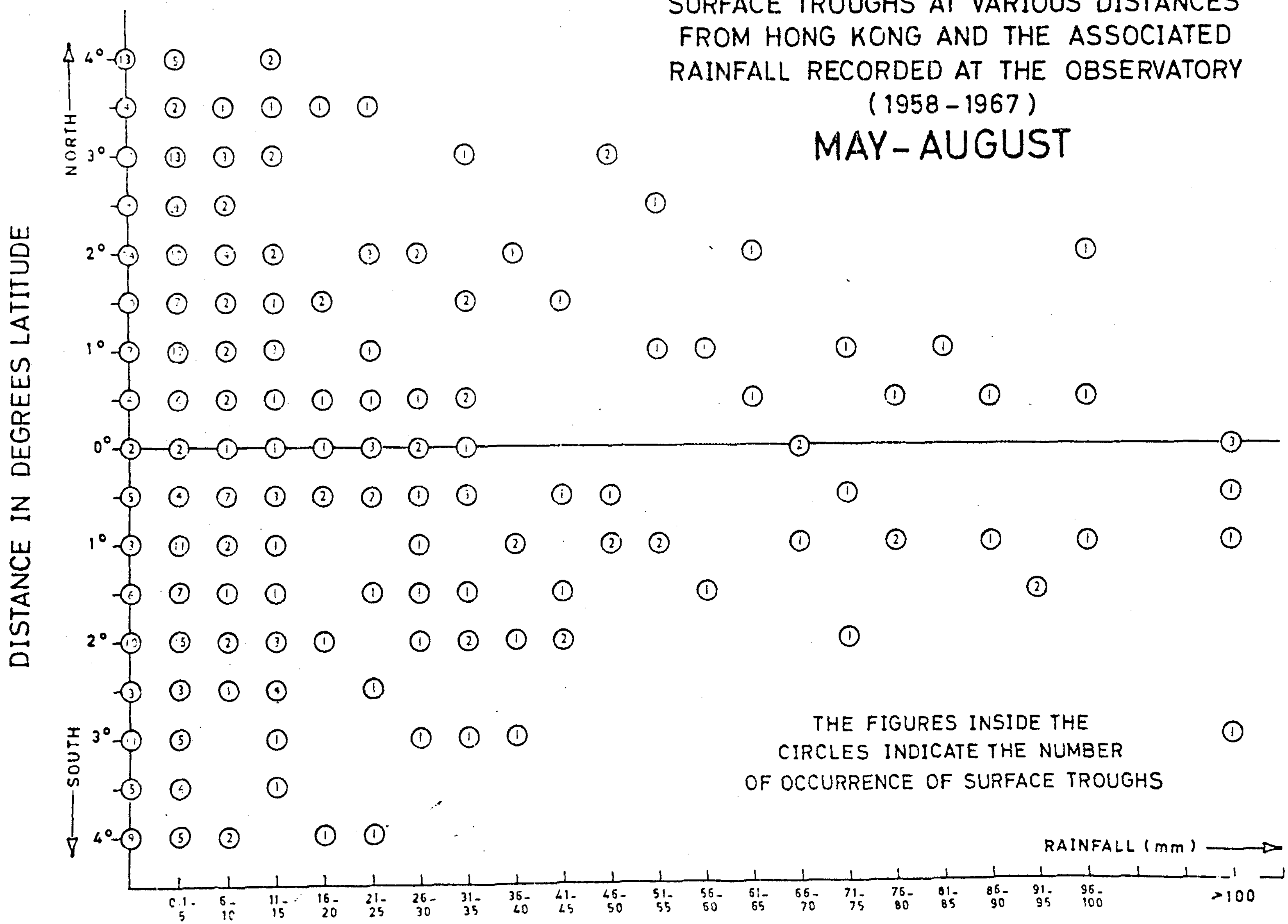
Figure 2

The northward displacement of the belt of rainfall maximum during May to July. Months and pentads are denoted by Roman and Arabic numerals respectively. (After Yoshino)



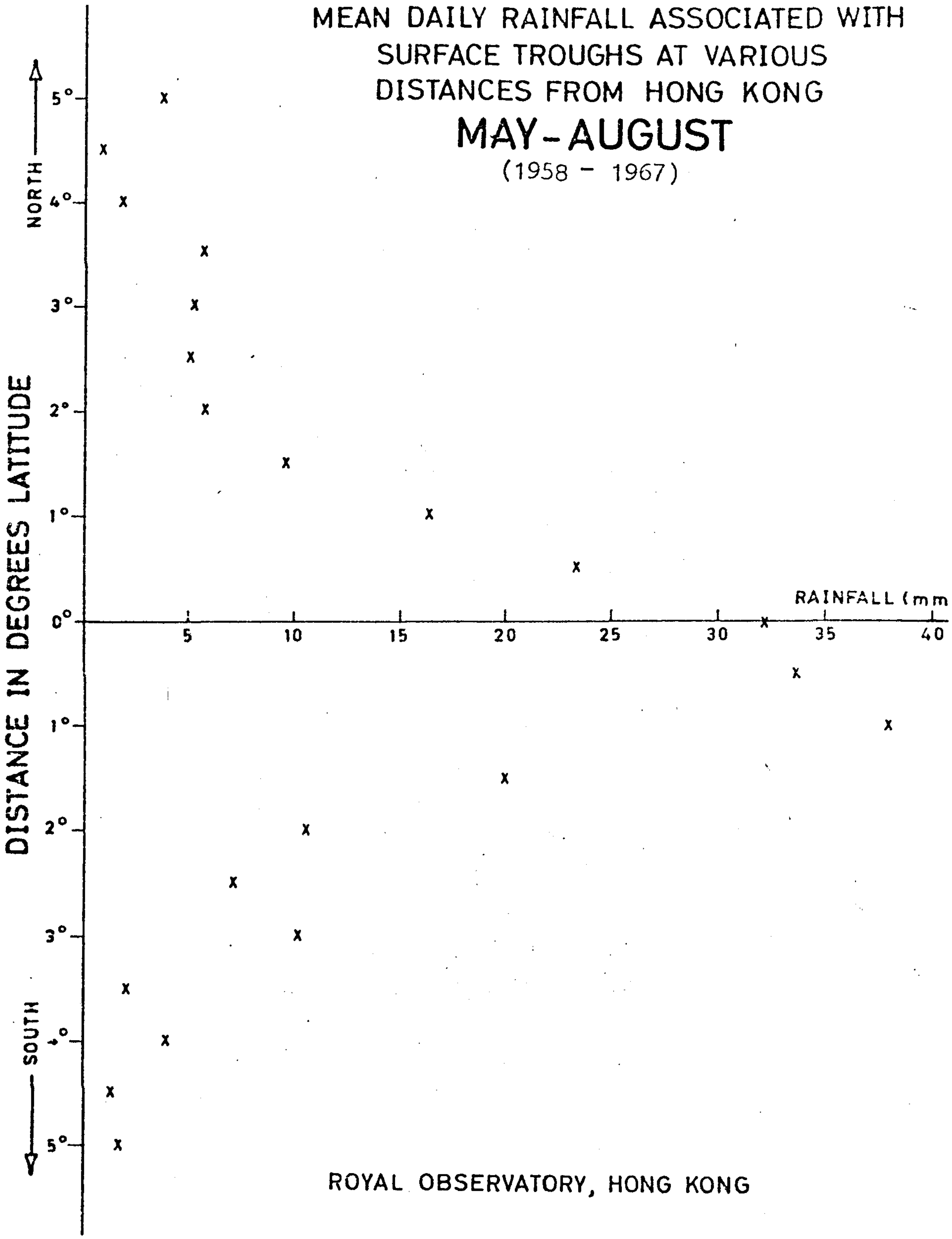
FREQUENCIES OF OCCURRENCE OF SURFACE TROUGHS AT VARIOUS DISTANCES FROM HONG KONG AND THE ASSOCIATED RAINFALL RECORDED AT THE OBSERVATORY (1958-1967)

MAY-AUGUST



THE FIGURES INSIDE THE CIRCLES INDICATE THE NUMBER OF OCCURRENCE OF SURFACE TROUGHS

Figure 4



ROYAL OBSERVATORY, HONG KONG

Figure 5 a

Global total of tropical storms relative to calendar year. (After Gray)

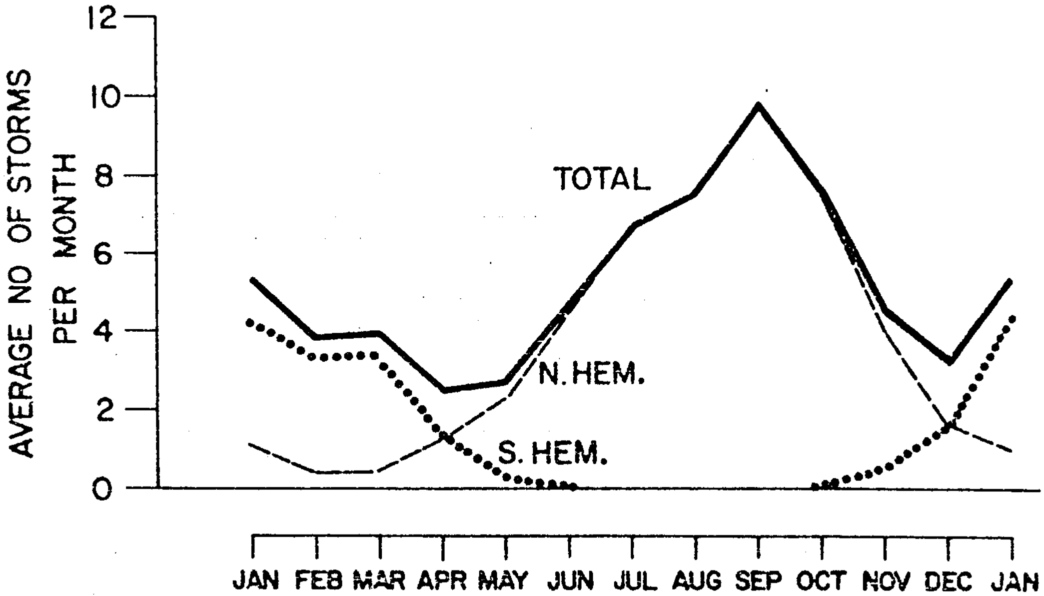


Figure 5 b

Global total of tropical storms relative to solar year. (After Gray)

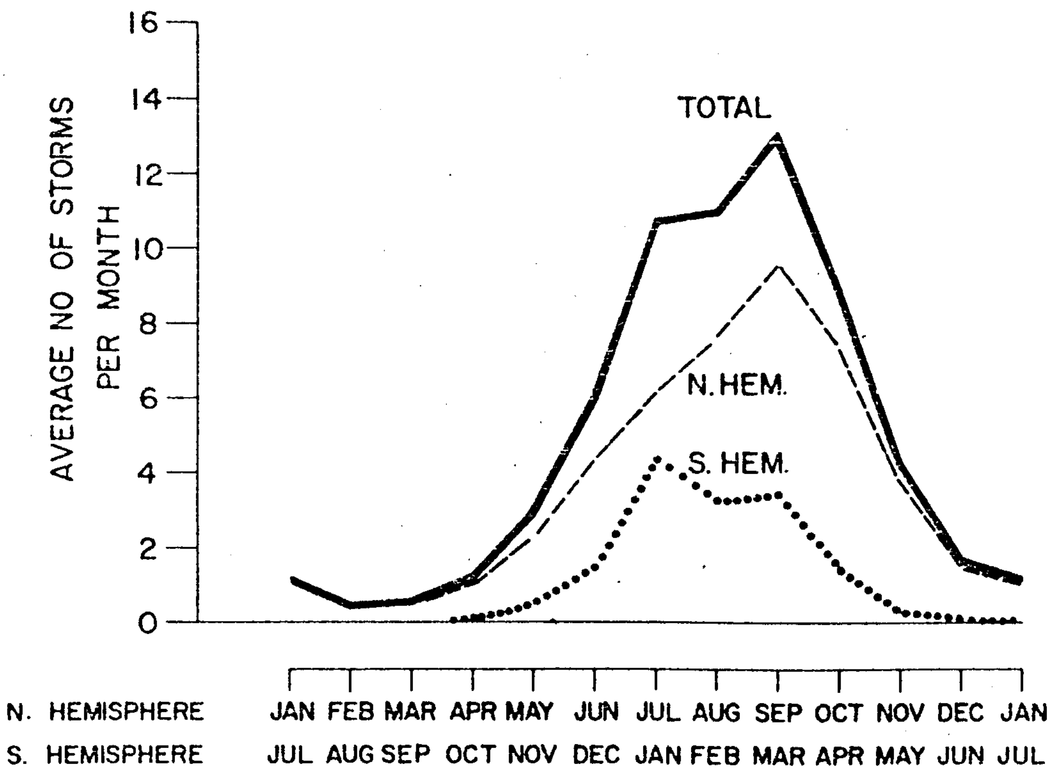


Figure 6

Portrayal of lower and upper tropospheric flow surrounding a tropical disturbance where the vertical wind shear above the disturbance would be small due to the passage of a westerly wind trough to the north. (After Gray)

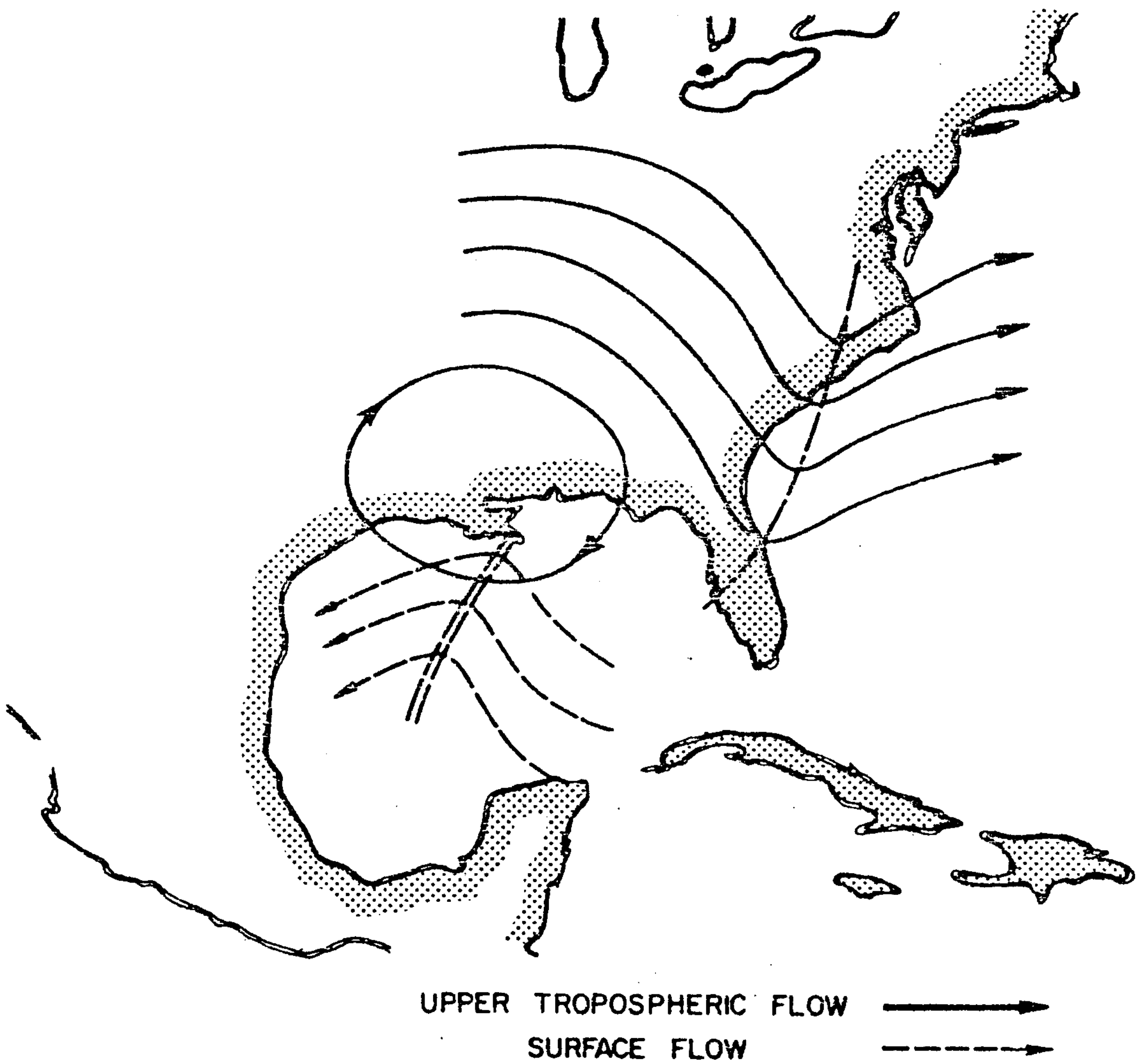


Figure 7

Mean hourly areal rainfall relative to the centre of the hurricane. (After Miller)

1 <.005	2 .01	3 .01	4 .04	5 .05	6 .05	7 0	8 0	9 0
10 .01	11 .02	12 .03	13 .06	14 .03	15 .01	16 <.005	17 0	18 <.005
19 .03	20 .04	21 .05	22 .06	23 .08	24 .08	25 .03	26 <.005	27 0
28 .06	29 .07	30 .11	31 .13	32 .18	33 .12	34 .04	35 .03	36 .01
37 .05	38 .07	39 .14	40 .26	41 .26	42 .10	43 .05	44 .02	45 <.005
.02	47 .04	48 .07	49 .14	50 .11	51 .06	52 .02	53 .01	54 0
55 .01	56 .01	57 .02	58 .04	59 .06	60 .02	61 .01	62 <.005	63 .01
64 .01	65 .01	66 .01	67 .01	68 <.005	69 .01	70 .01	71 <.005	72 .01
73 <.005	74 .01	75 .01	76 .02	77 .01	78 .01	79 .01	80 <.005	81 .01

Figure 8

Hurricane model surface wind field. (After U.S. Weather Bureau)

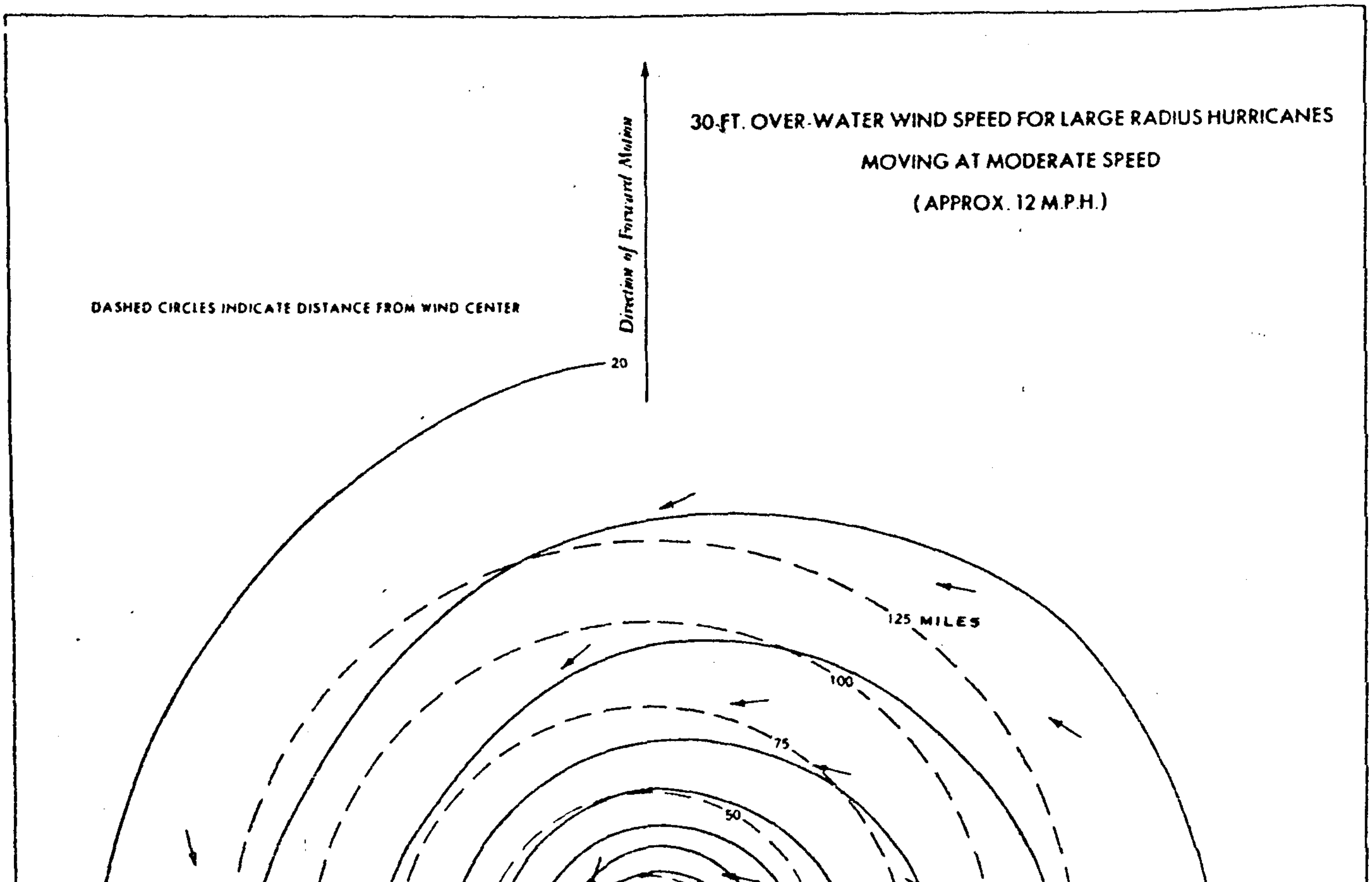


Figure 9

Variation of computed convergence rainfall intensity
with distance from centre of a model hurricane
(After U.S. Weather Bureau)

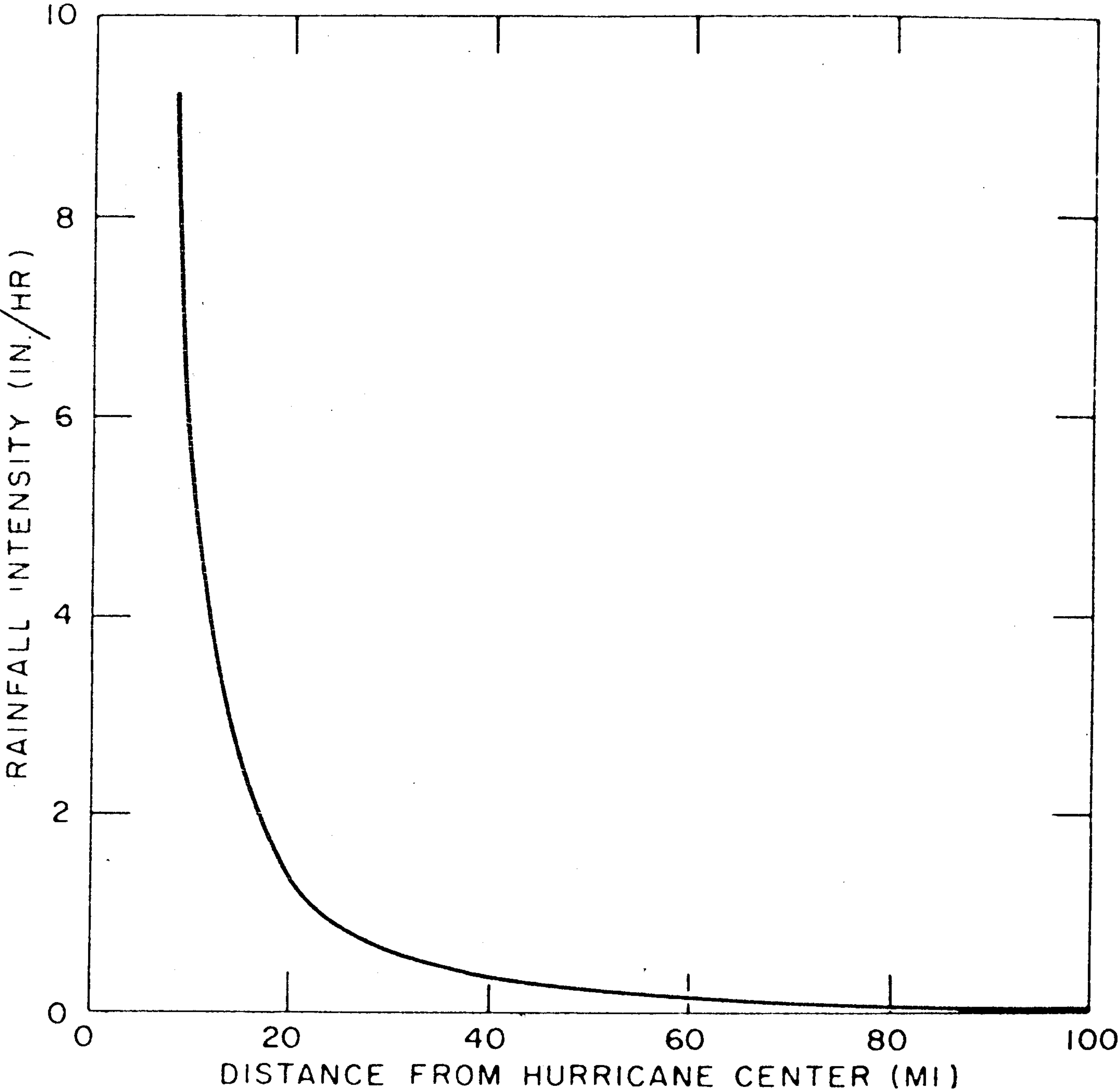
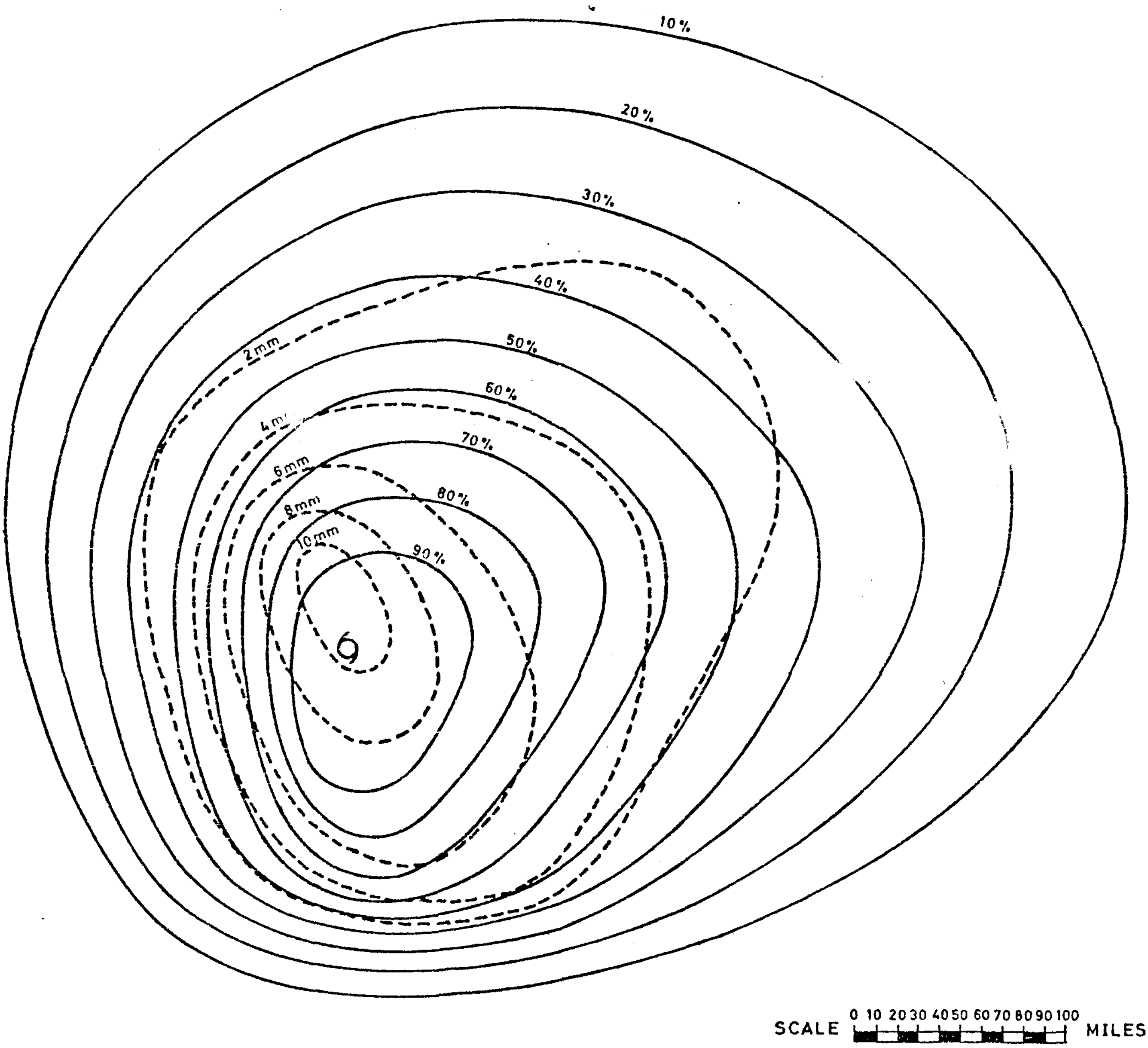


Fig. 10

PROBABILITIES AND MEAN HOURLY INTENSITIES OF MEASURABLE RAINFALL IN THE CIRCULATION OF A TROPICAL CYCLONE

(DATA INCLUDE ALL TROPICAL CYCLONES AFFECTING HONG KONG IN THE PERIOD 1947-1967)



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