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WORKING DRAFT

TYPHOONS ON THE SOUTHEASTERN COAST OF CHINA AND FORMOSA

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I. INTRODUCTION

Tropical cyclones of certain degrees of intensity are known as "typhoons" in the Far East, as "hurricanes" in the Atlantic Ocean and the West Indies, and as "cyclones" in the Indian Ocean. In the Philippines these storms are locally called "bayuios" and in Australia, "willy-willies."

The Chinese name for typhoons is "chu-feng"颶風. The character "chu" is composed of 具 for 俱, i.e., all, whole, altogether, and the radical "feng" 風 or wind. Thus "chu-feng" means "wind from all quarters."

In the dialect of Swatow, Amoy, and Formosa, a typhoon is called "hong-thai," the character "hong" 風 meaning "wind," and "thai," which has the same sound and the same tone as "thai," 胎 meaning "womb." Thus "hong-thai" means "the womb of the wind." For this Fukienese word, a new character, which is not found in old Chinese dictionaries, has been formed. It is "thai"颱, in which the radical character for womb has been changed into the radical "wind." This new character is now commonly used for the word "thai-feng," i.e., typhoon or 颱風 "big wind."[1]

Despite the different names, these tropical cyclones all have essentially the same origin, structure, and behavior. They are small

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[1]Father E. S. J. Gherzi, The Meteorology of China, Macau, 1951.

low-pressure areas forming revolving storms and are very nearly circular in shape. They are the most violent storms experienced by the mariner.

Typhoons in the Far East have been studied by Jose Algue and Louis Froc, as well as Charles I. Deppermann, Gherzi, Y. Horiguti, Co-ching Chu, and Heywood. Yet the exact cause of the origin of typhoons is not perfectly clear at present. The structure, energy supply, and the size and height of typhoons are still disputed subjects. In the first part of this study the author has introduced different hypotheses concerning the formation of typhoons, and has compared and evaluated them with the intention of presenting current knowledge about the formation of typhoons. The author has also collected different source material to show the structure and the routes of typhoons.

The southeastern coasts of China and Formosa have been attacked by typhoons very often. From the data gathered by the Royal Observatory of Hong Kong, the Weather Bureau of Formosa, and the Weather Bureau of Manila the author was able to calculate and analyze the frequency of typhoons which have hit the southeast coast of China and Formosa and draw certain conclusions. The relationship between the frequency of typhoons and the rainfall patterns in southern China and Formosa has been emphasized. Some notable destruction caused by typhoons is described here.

The last part discusses the fact that Formosa has been considered the "rice bowl" of the Far East, but from time to time typhoons have damaged the rice fields on the island. Using data covering a 51-year period, the monthly distribution of typhoons in Formosa has been indicated, and the relationship between rice planting in Formosa and the possible damage by the typhoons has been studied, and some concrete suggestions have been made.

II. TYPHOONS IN GENERAL

1. Theories on the Origin of Typhoons

The origin of typhoons is a controversial topic. Various hypotheses have been propounded by meteorologists. They can be summarized into three groups: convectional, mechanical, and frontal.

The Convectional Hypothesis

The convectional hypothesis of the origin of typhoons was apparently first proposed by Espy.[1] It received additional support from Ferrel[2] and Davis,[3] and it was generally accepted until the early 1930's. It was believed that the following series of events occurred in the equatorial trough: the warm moist surface air rose because of both insolation and widespread convergence, resulting in numerous cumulo-nimbus clouds and widespread heavy showers. Then the pressure began falling slowly (for reasons never very well explained) and the cumulo-nimbus clouds gradually coalesced. Thus, according to this hypothesis, the energy driving the typhoon is originally supplied by the heat of the calm air in the doldrums, and is afterwards largely

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[1] J. Espy, The Philosophy of Storms, Boston, 1841, p. 552.

[2] W. A. Ferrel, Popular Treatise of the Wind, New York, 1889, p. 313.

[3] W. M. Davis, Elementary Meteorology, Boston, 1894, pp. 206-208.

produced by the liberation of latent heat of condensation. The typhoon then develops true cyclonic violence by means of the deflecting force of the earth's rotation.

Now we know that typhoons do not as a rule develop close to the equator, since the deflective force of the earth's rotation is so slight in low latitudes that it does not favor the whirling motion characteristic of cyclone circulation. Also, this theory ignores certain factors in the genesis of cyclones and the very pronounced seasonal frequency distribution of typhoons. Therefore, this theory cannot be used to explain the origin of the typhoon.

Mechanical Hypothesis

The first mechanical hypothesis appears to have been suggested by Dave.[1] It was supported by Meldrum,[2] Doberck,[3] and Fassig.[4] This hypothesis assumes that typhoons are analogous to the whirls frequently set up by friction between opposing currents of water in streams. But Jeffries[5] points out that the whirls between opposing currents in streams never reach a greater velocity than the main currents.

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[1]H. W. Dave, Law of Storm, London, 1862.

[2]C. Meldrum, "On the Rotation of Wind Between Oppositely Directed Currents of Air in the Southern Indian Ocean," Proc. Met. Soc. (London), Vol. IV (1869), pp. 322-294.

[3]W. Doberck, The Low of Storms, 1st ed., Shanghai, 1887, 4th ed., Hong Kong, 1904.

[4]O. L. Fassig, Hurricanes of the West Indian Ocean, U.S. Weather Bureau, Bull. X, Washington, 1913, 28, plates 1-42.

[5]Harold Jeffries, "Theories as to the Origin of Tropical Cyclones" in Newnham's "Hurricanes and Tropical Revolving Storms," Air Ministry Geophys. Mem. (London), 2201 (1922), p. 105.

A modification of the mechanical hypothesis has been emphasized by Bjerknes.[1] According to him, typhoons are initiated by counter-currents of different temperatures. The colder air moves under the warmer, causing the latter to rise, and this process commonly induces condensation. The condensation of the water vapor then supplies the energy necessary to maintain the storms for a considerable length of time, once they are started.

A more recent addition to the mechanical or counter-current hypothesis is outlined by Bowie,[2] who believes that cyclones always originate between opposing winds.

Many Japanese scholars, such as Horiguti and Okada, have always held a more plausible modification of the mechanical hypothesis. Okada[3] states that within a narrow belt lying between the 25th parallel and the equator, and between the 120th and 150th meridians, easterly and westerly winds prevail along the parallels of latitude making small angles with each other. As high temperature and humidity are found in the area under consideration and both currents converge here, an ascending motion of air is produced. Since the counter-currents of air are not stable, any disturbance causes these currents to break up into several whirls. Many small whirls coalesce into a large whirl

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[1]J. Bjerknes, "Theory of the Polar Front," Monthly Weather Review, Vol. XLIX (1921), pp. 95-99; Vol. XL (1914), pp. 53-70.

[2]E. H. Bowie, "Formation and Movement of West Indian Hurricanes," Monthly Weather Review, Vol. L (1922), pp. 173-179.

[3]T. Okada, "The Present Status of Typhoon Investigations in Japan," Proceeding of 5th Pacific Congress (Canada), Vol. 3 (1933), pp. 1981-1983.

which becomes in turn a typhoon, providing the conditions in the neighborhood are favorable, and the center of the typhoon becomes deeper and the isobars take on a circular form. The progressive motion of a typhoon as a whole then is controlled by the air currents which give birth to a tropical storm.

This theory seems to fit the observed facts, but it still has some difficulty in illustrating many phenomena. In order for a typhoon to exist there must be an uplift over a considerable area, together with an air stream moving in such a direction as to bring the center of upheaval into a latitude where the force of the earth's rotation is enough to start the spiraling of the air around the center.

Frontal Hypothesis

In recent times there has been a growing tendency toward general agreement among meteorologists that typhoons are of frontal origin. This concept is not a new one. It started from the theory of the Norwegian School. Professor V. Bjerknes had studied this particular theory and had already mentioned an "Equatorial Front" in a lecture printed in Nature, June 24, 1920. Recently Bergeron published an article entitled "On the Physics of Fronts."[1] In the conclusion he says, "All tropospherereic cyclonic disturbances seem to be, directly or indirectly, of frontal origin." Since the actual known facts concerning them are relatively few, a great variety of opinion about the origin of typhoons has arisen.

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[1]T. Bergeron, "On the Physics of Fronts," Bull. Amer. Met. Soc. (1937), p.275.

Father Gherzi,[1] who has long studied typhoons along the China coast, stated that a typhoon is a "disturbance" in a trade wind air mass traveling with that air mass. In the Caroline Island region the air is usually calm and consequently accumulates more and more heat and humidity. He found that the trade wind lies on the north side of the long, warm, and damp air wall, and that a southwest monsoon, arriving from the equatorial regions and from the southern hemisphere, lies on the other side. Owing to the direction of light wind observed over the Caroline Islands, the air overlying them belongs to the trade wind and is greatly attenuated in its course by the geographical influence. A freshening in the trade wind could perturb these almost stagnant parts of the extreme southern border of the trade wind mass and so produce a whirl which would be driven away by the more active part of the same trade wind mass on a westerly track. A typhoon, therefore, would result. Although Father Gherzi does not believe the Norwegian frontal theory of typhoon origin, he still recognizes the existence of fronts.

Father C. E. Deppermann of the Manila Observatory has published a series of books about typhoon origin and structure. At the present time his theory seems more advanced than those of others and is recognized by many meteorologists. His idea is based on V. J. Bjerknes' front theory. Evidence of frontal origin is seen in the somewhat unequal distribution of rainfall and in the wind discontinuities which he has observed in Philippine typhoons.[2]

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[1]E. Gherzi, Typhoon and Front, Zi-Ka-Wei Observatory, Shanghai, 1933.

[2]C. F. Deppermann, Outlines of Philippine Frontology, Manila, 1936; Wind and Rainfall Distribution in Selected Philippine Typhoons, Manila, 1937.

According to Deppermann's experience, no case came under his observation in the Philippine region where a typhoon did not originate in a front. In no case did a typhoon clearly originate within a homogeneous air mass, even the moist southwest monsoon. When the typhoon started, the southwest monsoon, which is very moist even in high altitudes, met with the trade winds or another air mass at a considerable angle, or at least a surge of the one caused a steeper pressure gradient between the two, and thus conditions were favorable for the forcible uplifting of one air stream over the other. The front covered a considerable area.

The southwest monsoon is generally more moist and is found at a greater altitude than either the trades or the northern winds, both of which usually become very dry above 1.5 km. As soon as the southwest monsoon reaches the point of condensation, the latent heat is liberated. The process tends to warm the air; thus the southwest monsoon seems to be a rather warm air mass. In other words, the origin of typhoons is coincident with a surge of southwest monsoons.

Typhoons owe their violence to enormous amounts of heat energy. Therefore, they can develop only in the presence of the hot, moist, and unstable air found in certain sections of the equatorial front.

A consideration of the three chief theories of the origin of typhoons reveals that each is supported by eminent meteorologists. However, it seems that the frontal theory is the most satisfactory of the three, for it is capable of explaining the genesis of cyclones, the source of energy, and the frequency and distribution of typhoons.

Since typhoons originate in the low latitudes and traverse remote oceanic areas, the acquisition of data required for a conclusive evaluation of many theories concerning their origin and structure and for a solution of the forecast problem has been difficult or impossible. This is especially true in respect to information about the upper air.[1]

However, the most recent and persuasive theories are not substantiated. If a detailed observational program were initiated for short periods of time in low latitudes during the typhoon season, the new data would prove invaluable in deriving new ideas and further clues about the origin and structure of typhoons.

2. Energy Supply and Structure of Typhoons

A typhoon is a violent tropical cyclone which has exceptionally low pressure in the center. A large cyclone moving from low latitudes to high latitudes requires an enormous amount of energy in order to produce gales and torrential winds.

Where does this energy come from? There is still some question regarding its origin. Horiguti[2] does not believe that discontinuity of temperature exists in the typhoon area. He believes that the principal source of energy is the heat liberated by the condensation of water vapor. The water content in the atmosphere is supplied from the ocean. The energy of the typhoon is lost through radiation and the

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[1]Gordon E. Dunn, Tropical Cyclones, Compendium of Meteorology, 1951, p. 900.

[2]Yosiki Horiguti, "Some Notes on Typhoons," Proceedings of the 3rd Pacific Science Congress (Tokyo), Vol. 2 (1926), p. 1421.

friction of the winds. Both the gain and the loss of energy have been calculated, and the results coincide. A typhoon is, so to speak, a complete heat engine, in which the heat is supplied through the water vapor. The refrigerator is the upper atmosphere. The heat energy is converted into mechanical energy in the form of winds, horizontal and vertical.

Dines[1] and Davis,[2] who have advocated that condensation alone is sufficient to provide the energy for a typhoon, apparently considered the maintenance of a storm after the whirl is established rather than the energy involved in setting the vast mass of air into rapid motion. Once the whirl is well established, the energy requirements are far less.

Shaw[3] states that the chief cause of the death of cyclones is their failure to secure a sufficient supply of warm, moist air. The condition is brought about when the typhoon moves too far from the ocean or other source of moisture, or when it comes into too cold a region where all the winds are cold.

Gherzi stated that the real and principal source of energy in a cyclone resides in condensation with its released latent heat.[4] He believes that "rain caused wind to be formed."

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[1] W. H. Dines, "The Energy of Cyclones," Monthly Weather Review, Vol. 49 (1921), pp. 3-4.

[2] W. M. Davis, Elementary Meteorology, Boston, 1894, p. 200.

[3] N. Shaw, "The Birth and Death of Cyclones; Introduction to Newnham's 'Hurricanes and Tropical Storms'," Geophysical Memoirs, No. 19, Meteorological Office Publication 2201, London, 1922 (M. Visher's report).

[4] E. Gherzi, The Meteorology of China, Macau, 1951, pp. 249-50.

Deppermann[1] stated that in low latitudes, where temperature differences in the air stream, at least at the surface, are almost negligible, the main energy is derived from the condensation of water vapor from the storehouses of humid air. This requires strong convection upward rather than horizontal translation, i.e., the southwest monsoon contributes the greatest share of the energy of the storm by the condensation of its abundant water vapor. The convergence is due not so much to influence or lack of it from the earth's rotation but to the decided upward convection resulting from condensation of profuse amounts of water vapor present, especially in the southwest monsoon.

All opinions seem to agree with the frontal origin of typhoons. According to direct observation at Manila,[2] the southwest monsoon has great relative humidity all the way up, and does not show the tendency for rapid decrease of wetness aloft that characterizes Np and Tm air masses. Hence the latent power is stored in the southwest monsoon air mass.

In the center of the typhoon circulation there is an area of relative or absolute calm known as the eye of the storm. The diameter of the eye is variable. It may be three or four miles in a young typhoon and it may increase from 40 to 80 miles in diameter, but usually it is about 12 to 15 miles. During the passage of the typhoon, the calm may last a few minutes or it may last more than an hour, depending upon the dimensions of the eye and its speed of displacement. The eye of

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[1] C. E. Deppermann, Outline of Philippine Frontology, Manila, 1936, pp. 17-23.

[2] C. E. Deppermann, The Upper Air at Manila, Manila, 1934.

any well-developed storm generally decreases in diameter as the storm intensifies.

The eye is characterized by a sudden decrease in wind speed from a very high to a very low velocity. The air may even become calm in the eye, but immediately surrounding the eye the winds are strong. Sometimes patches of blue sky are observed from a station during the passage of the eye.

In the eye of a well-developed typhoon like "Marge" in August 1951, the eye was clear, surrounded by a vast coliseum of cloud whose walls rose to a height of 35,000 feet. Clouds in the undercast layer were grouped in bands which spiraled cyclonically about the opening. In the center of the eye the stratocumulus overcast bulged upward in a dome-like fashion to a height of 8,000 feet (Figure 1).

The lowest pressure usually can be observed in the eye of the typhoon (Figure 2), where rains usually stop or decrease to a light drizzle. The few exceptions may be due to local or orographical influences. After the eye has passed, the pressure rises abruptly, extremely high winds begin blowing in the direction opposite to that preceding the passing of the eye, heavy rains pour down, and low clouds cover the sky again.

The temperature condition in the eye is very interesting. During the passage of the center calm in the Manila typhoon of October 18, 1882 the temperature rose suddenly from 24° to 31.5° C. The relative humidity, which was almost 100 per cent immediately before and after the calm, dropped to 49.7 per cent. The rise in temperature may be

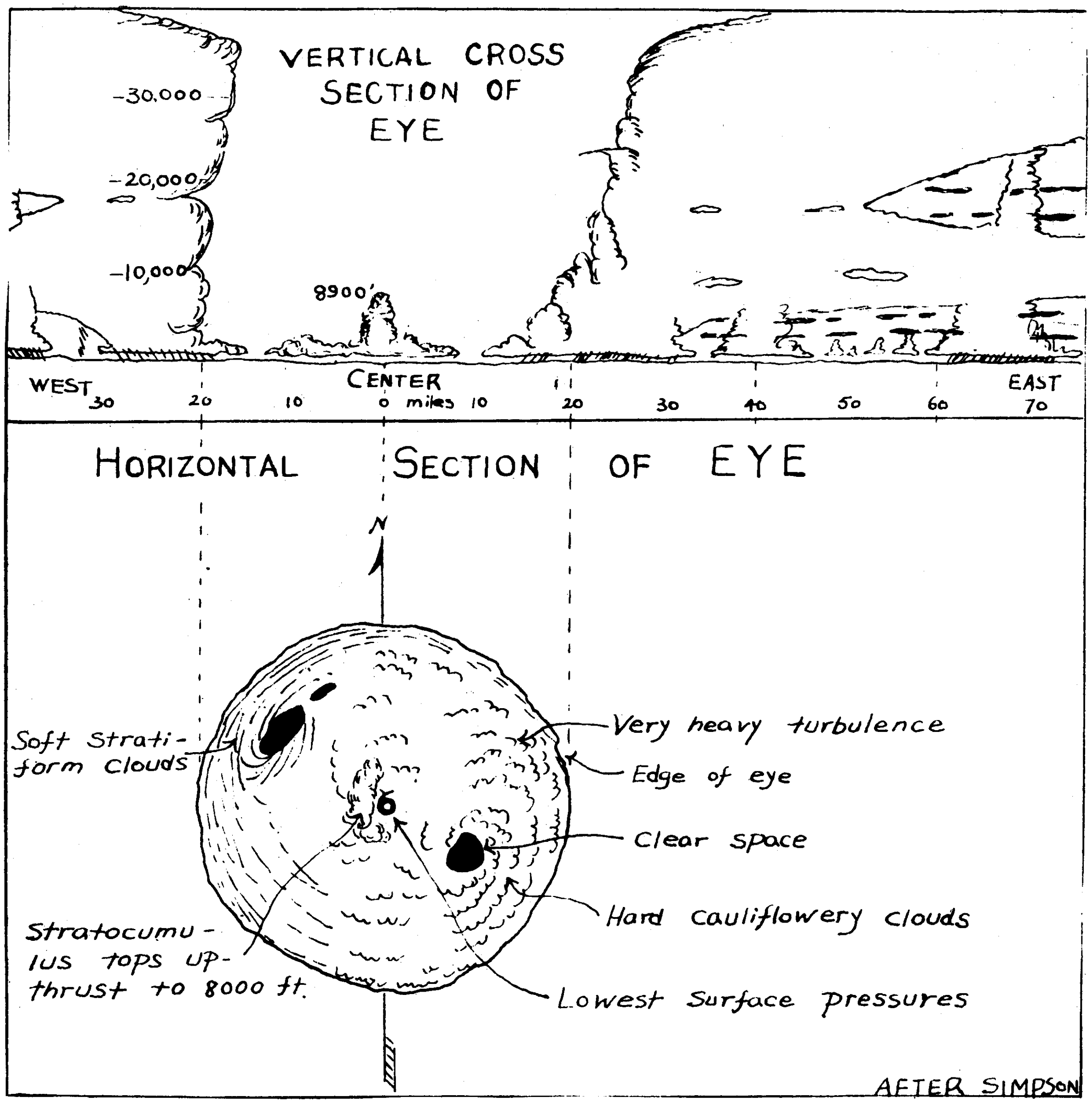

Figure 1. Horizontal and Vertical Section of the Eye of Typhoon "Marge"

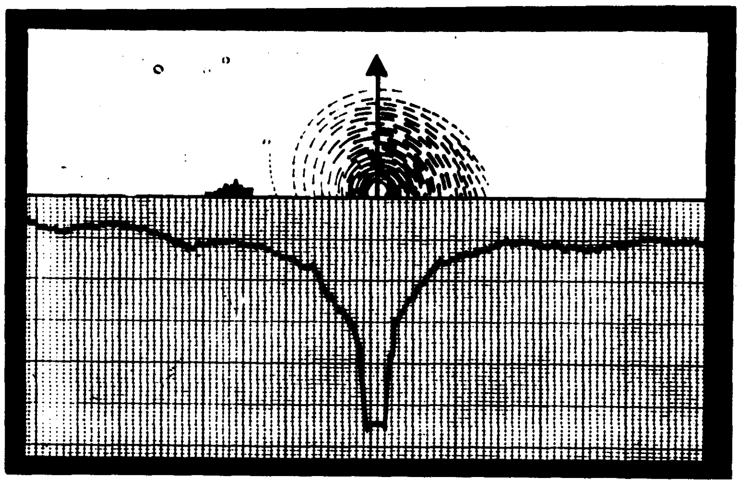

Figure 2. The Relationship Between the Eye of the Typhoon and the Lowest Pressure (after U. S. Navy)

due to insolation according to Algue, but Hauritz states[1] that in the eye of the storm there is a downward current which brings warm and dry air to the ground; both Deppermann[2] and Okada[3] have found that a warm core is by no means an invariable feature. Warming by descent would involve a decrease in relative humidity.

Heywood observed a typhoon on the afternoon of November 23, 1939. When the center calm was directly over Hong Kong he found that

> . . . the warming temperature was not due to an increase in incoming radiation, for the sky remained overcast throughout the calm. The rain ceased at this time, but the comparative coolness of the air outside the calm cannot have been due to cooling by evaporation from falling rain, for on the peak the air remained saturated throughout. The fact that similar changes occurred on a mountaintop and near sea level rules out any local foehn effect.[4]

Gherzi[5] explained that the slight increase in temperature is due to the lack of evaporation following a decrease in wind or, during the

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[1]B. Haurwitz, "The Height of Tropical Cyclones and the Eye of the Storms," Monthly Weather Review, Vol. LXIII (February 1935), pp. 45-49.

[2]C. Deppermann, Some Characteristics of Philippine Typhoons, Manila Observatory, 1939.

[3]T. Okada, "On the Eye of the Storm," Mem. Imperial Marine Observatory (Kobe), Vol. 1, p. 27.

[4]G. S. P. Heywood, "Some Features of a Typhoon," Bull. of Amer. Met. Soc., Vol. 23 (1942), p. 51.

[5]E. Gherzi, The Meteorology of China, Macau, 1951, pp.217-219.

day, the influence of the sun. He suggested that the temperature of the typhoon proper is between 25°C. (77°F.) and 27°C. (80.6°F.). This is why people feel cooler when a typhoon arrives in Shanghai, for the mean temperature of July and August is 28°C. (82.4°F.) in Shanghai. The same typhoon will give an impression of warmth in Japan, because the mean temperature there is lower than the temperature of typhoons.

According to Simpson's report[1] on a mature typhoon of August 1951:

> The walls of the eye on the west side were steep, either vertical or overhanging, and had a soft stratiform appearance. On the east side, however, clouds were more a cumuliform type with a hard cauliflowery appearance. In this sector the walls of the eye rose with a gradual concave slope to the upper rim. The overall appearance indicated that the axis of symmetry (in the vertical plane) was tilted to the east or northeast.

This report gives a vivid impression of the shape of the eye.

Typhoons vary greatly in their size, extending from 50 to 1,000 miles in diameter, but the region of greatest destructiveness is a strip from 10 to 30 miles wide on either side of the eye of the storm, although the adjacent country on either side of the zone may suffer almost as much. While storm damage by waves and wind may be limited to a belt 30 to 50 miles wide, torrential rains may effect a wider damage. The average size of typhoons also varies with the season. Those of the main storm season are generally larger than those of the less stormy months.

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[1] R. H. Simpson, "Exploring the Eye of Typhoon 'Marge' 1951," <u>Bull. of the Amer. Met. Soc.</u>, Vol. 33 (1951), p. 290.

Early opinions often suggested that typhoons are very shallow disturbances. The height of a typhoon was thought to be so low that it could not cross a mountain range 3,000 feet high. Such opinions were based on the observation that typhoons rapidly decrease in intensity when they pass over land, particularly in crossing even a small mountain range.[1] Both Gherzi[2] and Deppermann[3] are suspicious of the theory of mountain influence. Deppermann stated that "while a typhoon does generally successfully pass over our mountain ranges, still it suffers some loss in minimum."

Many meteorologists have made estimates on the height of typhoons based on calculations concerning temperature variations and on observations of clouds around a cyclone.[4] They consider that a typhoon has great vertical extent, at least 13,000 feet, and Selga has pointed out that its height may reach six miles, or 31,680 feet.[5]

While the figures on the height of typhoons are still uncertain, we can say that the height of some typhoons is around ten kilometers, or about 31,000 feet.

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[1]John Eliot, Handbook of Cyclonic Storms in the Bay of Bengal, Calcutta, 1900, p. 228.

[2]E. Gherzi, The Meteorology of China, Macau, 1951, p. 222.

[3]C. Depperman, op. cit.

[4]B. Haurwitz, op. cit., p. 47; and G. S. P. Heywood, op. cit., pp. 47-52.

[5]H. Selga, "The Height of the Typhoon," Proc. 3rd Pan-Pacific Science Congress (Tokyo), Vol. 2 (1926), pp. 1409-1416.

3. Mean Tracks and Speed of Typhoons

The mean tracks of typhoons are hard to trace. There are many differences of opinion concerning the classification of storms, and what one authority considers to be just a severe storm, another may regard as a typhoon. However, one can find many good charts illustrating the mean tracks of typhoons. Froc's atlas of the tracks of 620 typhoons (Zi-Ka-Wei Observatory) is an extremely valuable one, but so many charts, each covered with a maze of tracks, are bewildering, as he himself remarks.

Claxton's map[1] covers the period from 1884 to 1930, and it is one of the longest charted records we have. This chart shows the prevalence of typhoons in different regions of the Far East for each month of the year. This is an excellent chart of areas affected, but it does not show the actual tracks of typhoons. The information for Figure 3 was obtained originally from Claxton's chart.

Typhoon tracks can be divided into two directions: (1) those which move from east of the Philippines to the west or northwest and into the southern part of the China Sea or to Indo-China and (2) those which are parabolic in shape, moving first west and then north. Upon crossing the latitudes 20° N. to 25° N., the latter typhoons recurve to the east and northeast. These typhoons usually begin with a variable direction and low velocity. After moving to the middle latitudes and recurving their course, they begin to spread out and diminish in intensity, although they may still be violent.

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[1]T. F. Claxton, Isotypes, Hong Kong, 1932.

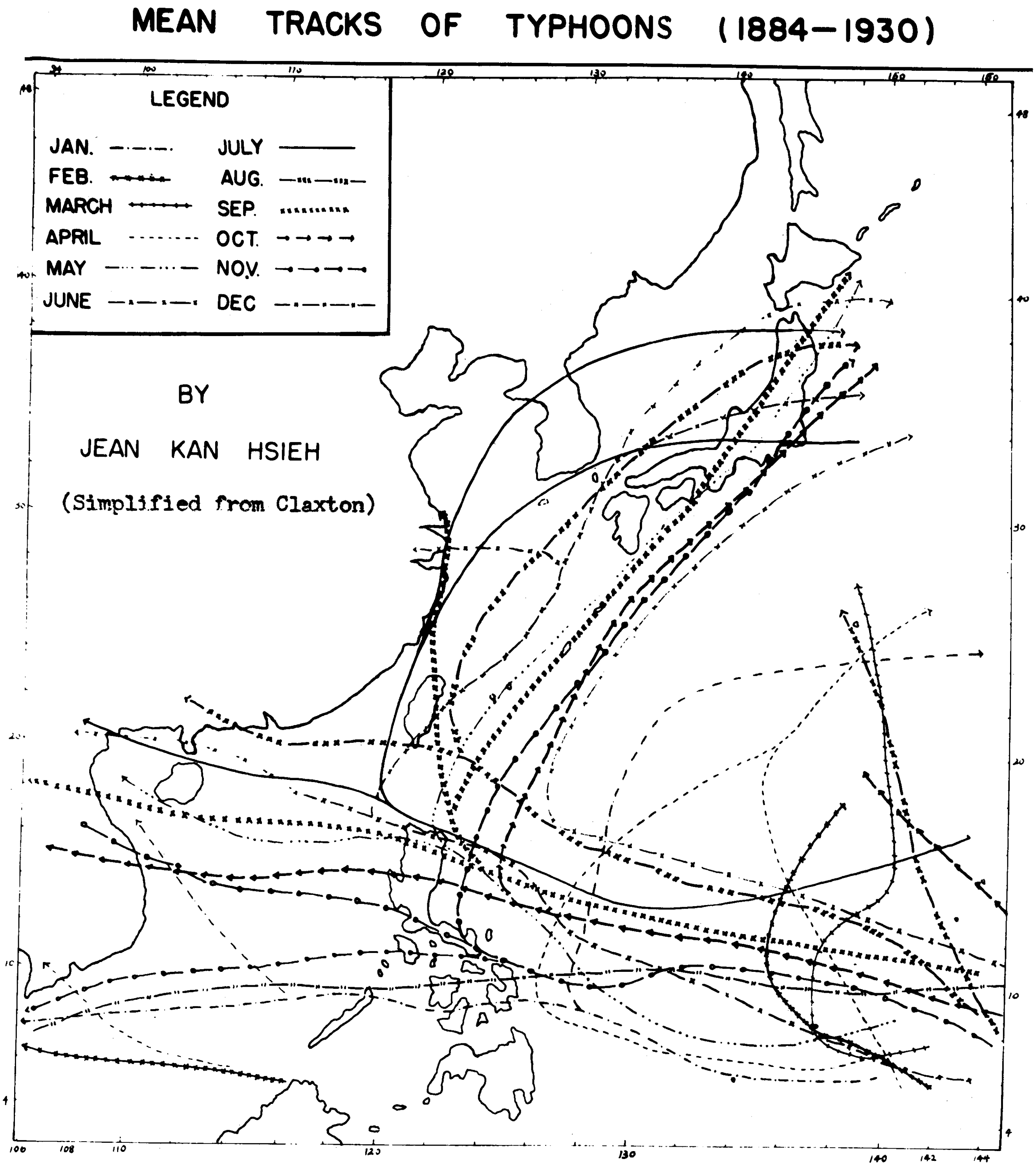

Figure 3. Mean Tracks of Typhoons (1884 - 1930)

The movement of a typhoon is controlled by the air mass to which it is related. According to the frontal theory, at first the typhoon often goes west or northwest along the equatorial front and then, after it reaches the high latitudes, it turns northeast along the Np or Tm front. Sometimes the typhoon goes directly to the west or the northwest when the Tm air mass covers the area of southern China. In winter when the continental air mass is strong enough to prevent the advance of a typhoon, it often goes directly toward the west.

Typhoon movements generally follow a regular route. The path of a storm is limited by the Siberian anti-cyclone on the one hand and by the Pacific anti-cyclone on the other.

Typhoons vary greatly with respect to speed of travel. Some remain almost stationary for a day or two, while others have been known to travel at the rate of fifty miles per hour, or 1,200 miles per day. Their mean speed also varies with the seasons, particularly in certain portions of their courses. In general, the greatest speed is achieved during the main typhoon season, from July to October. A storm also travels much faster when it is going northeastward, after recurving.

Formerly "stationary cyclones" were thought to occur, but the studies of recent years indicate that, although many storms move very slowly at first and sometimes while recurving, none are entirely stationary. Some oscillate back and forth, particularly while forming and also while recurving. Some storm courses show loops, which give the impression that the storm is stationary.

The unusually swift storms, those progressing more than 300 miles a day in the tropics, or more than 600 miles a day after recurving, apparently are related to a peculiar combination of changing air pressure conditions. Swift storms either move into an area of extremely low pressure or are crowded forward by advancing areas of abnormally high pressure.

III. TYPHOONS ON THE SOUTHEASTERN COAST OF CHINA

1. Annual Frequency and Monthly Distribution of Typhoons

There are several differences of opinion concerning the annual frequency of typhoons, for a storm which one persons considers a true typhoon may not be regarded as such by another. The variation in the annual number of typhoons reported by different authorities for certain years is listed in the following table:

Table 1

Author	Period	No. of Years	Total No. of Storms	No. of Storms for Each Year
Algue	1880-1901	22	468	21.3
Froc	1893-1918	26	619	23.8
Visher	1880-1920	41	917	22.4
Chu	1904-1915	12	247	20.5
Lu	1907-1936	30	637	21.2
Starbuck	1884-1896 1905-1939 1946-1947	50	989	19.7
Shih	1895-1945	51	875	17.1

From the foregoing list it appears that, on the average, the annual frequency of typhoons is from 17.1 to 24.5. The figure varies considerably and there is no indication of any cycle. As a rule, at least twenty typhoons are detected each year in the Far East; however, only a small number of these reach the southeastern coast of China. In Hong Kong 74 typhoons were recorded during the 62 years from 1884 to 1941 and 1946 to 1949.[1] Thus typhoons have occurred there on an average of a little oftener than once a year.

As to monthly distribution, typhoons are most frequent from July to October. This four-month period is commonly called the typhoon season in the Far East. The frequency of typhoons in each month is expressed in percentages of the annual total in the following table (Table 2).

As a whole these figures, which have been gathered from various authorities, agree well in percentage, although there are a few discrepancies which are mainly due to the differences in the years recorded. The maximum frequency is either in August or September, and the minimum is in February, March, and April.

The frequency of typhoons is related to the air masses. In winter the continental air mass controls most of the area in the Far East, and typhoons occur less frequently. The only place where a few small storms can be created is at the latitude 5° N., but these storms disappear very quickly. In summer the southwest monsoon enters in the low latitudes of the northern hemisphere, and the continental air mass retreats to the northwest. The maximum frequency of typhoons is thus from July to October. There is another interesting phenomenon here. The temperature of the ocean is warmest in August and coolest in

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[1] G. P. Heywood, Hong Kong Typhoons, Royal Observatory, Hong Kong, 1950, p. 3.

Table 2

PERCENTAGE OF MONTHLY DISTRIBUTION OF TYPHOONS FROM VARIOUS AUTHORITIES*

Authorities and the Periods Covered by Them (no. of yrs. given in parentheses)

Months	Algue 1880-1901 (22)	Okada 1897-1911 (15)	Froc 1893-1918 (26)	Visher 1880-1920 (41)	Chu 1904-1934 (31)	Lu 1907-1936 (30)	Starbuck 1884-96 1905-39 1946-47 (50)	Shih 1895-1945 (51)
Jan.	2	0.4	5	4.0	1.6	1.9	0.9	
Feb.	0	0.0	3	1.9	0.8	0.9	0.3	
Mar.	1	1.2	3	2.3	1.2	0.8	0.7	
Apr.	2	0.8	2	2.6	1.2	2.0	1.2	
May	5	3.6	5.5	5.1	4.1	3.5	4.4	4
June	9	4.5	5.5	6.1	5.7	5.5	6.2	6
July	16	11.7	14	15.4	16.4	16.2	17.9	19
Aug.	17	22.3	15	16.0	21.2	19.2	20.1	22
Sept.	19	22.7	18	18.3	19.2	18.6	19.9	21
Oct.	14	21.1	16	14.4	15.1	15.6	19.5	14
Nov.	11	8.9	8	8.6	8.2	10.3	9.7	9
Dec.	5	2.8	5	5.2	5.3	5.5	4.1	5

*Algue, Cyclones of the Far East, Manila, 1904, p. 86; T. Okada, "The Present Status of Typhoon Investigation in Japan," Proceedings of the Fifth Pacific Scientific Congress (Canada), Vol. 3 (1933), p. 1981;

Louis Froc, Atlas of the Tracks of 620 Typhoons, Zi-Ka-Wei Observatory, Shang-hai, 1920; S. S. Visher, "Notes on Typhoons, with Charts of Normal and Aberrant Tracks," Monthly Weather Review, Vol. L (November, 1922), pp. 584-589; Co-Ching Chu, "Climatology of China," Meteorological Institute of China, Vol. 7 (1936); A Lu, "The Typhoons of the Far East," The Meteorology Magazine, Vol. 14, No. 6 (1939), p. 263; Hen-han Shih, "Typhoons Which Have Raided China within 51 Years," Hsueh-i Tsa-chih, No. 8 (1946), p. 5.

February, coinciding with the months of greatest and least frequency of typhoons.

Taking Hong Kong as a representative station on the southeastern coast of China, the number of typhoons recorded for each month in the years 1884 to 1941 and 1946 to 1949 is as follows:

Table 3

J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Total
0	0	0	0	0	2	16	20	25	8	3	0	74

Typhoons occur with greatest frequency in August and September. As yet none have been recorded during the period from June to November inclusive, and the great majority have occurred in the months of July to October. But average figures are sometimes misleading, for typhoons recur at extremely irregular intervals, and on several occasions as many as three typhoons have occurred in a single month (September 1887, September 1894, September 1906, and July 1923).[1]

Figure 6 takes us a step further in the analysis of the frequency of typhoons, showing the number of typhoons recorded at Hong Kong in each five-day period. Typhoons are rare in June and the first half of July; then there is a sharp rise in the frequency curve during the second half of July. This curve falls off about the middle of August and rises again in September. In October the frequency diminishes steadily, and in November only an occasional typhoon is recorded. The decrease of the curve in the middle of August is connected with

[1] Ibid.

the fact that at this time of year there is a tendency for typhoons to pursue a northwesterly track toward the Eastern Sea or Japan so that the number moving WNW toward the southeastern coast of China is temporarily diminished.

If we use the data recorded by the weather bureau of Formosa and reported by Shih,[1] we can analyze the frequency of typhoons on the southeastern coast of China in more detail. According to this data, within the 51-year period from 1895 to 1945 there were 875 typhoons in East Asia--an average of 17 per year. Most of the typhoons either blew themselves out or remained over the ocean. Only 291 reached the mainland of China, making an average of six storms per year, while Formosa suffered 98 typhoons in all, an average of about two each year.

Dividing the mainland of China into four sections, namely, Hainan Island, Kwangtung, Fukien, and Chekiang and the area north of it, the number of typhoons which reached each section for 51 years in terms of months is given in Table 4. According to this table, typhoons reached the mainland of China in July, August, and September more frequently than in other months. If we look at the July column we notice that the southern areas, with the exception of Hainan Island, suffered more typhoon storms than the northern areas.

In the month of August the number of typhoons which reached each section was the same as in July. In September the southern sections again were hit more frequently.

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[1]Y. N. Shih, "Typhoons Which Have Raided China within 51 Years," Hsueh-i Tsa-chih, No. 8 (1946).

Table 4

MONTHLY DISTRIBUTION OF TYPHOONS ON THE SOUTHEAST COAST OF CHINA[1]

	Chekiang and Area North of Chekiang	Fukien	Kwangtung	Hainan Is.	Number of typhoons which reached the mainland of China
May	-	1	4	2	7
June	-	4	7	4	15
July	19	29	35	10	93
Aug.	29	30	27	7	93
Sept.	5	21	22	9	57
Oct.	1	4	11	8	24
Nov.	-	-	2	-	2
51-year Total	54	89	108	40	291

Table 5 tells by per cents what proportion of the total number of typhoons striking a given area occurred in a given month. From this table we can draw these conclusions:

1. Eighty-four per cent of the total number of typhoons were concentrated in the months of July, August, and September. This figure includes the whole northeastern coast of China.

2. For the section of Chekiang and the area north of it, August was the month in which there were the most typhoons, and July was

[1]Computed from the data of the Weather Bureau of Formosa and Shih, *op. cit.*

Table 5

MONTHLY FREQUENCY OF TYPHOONS IN SOUTHEASTERN CHINA
(in percentages)

	Chekiang and Area North of Chekiang	Fukien	Kwangtung	Hainan Is.	Number of Typhoons Which Reached the Mainland of China
May	-	1	4	5	2
June	-	4	6	10	5
July	35	33	32	25	32
Aug.	54	34	25	18	32
Sept.	9	24	20	23	20
Oct.	2	4	10	20	8
Nov.	-	-	2	-	1
Whole Year	100	100	100	100	100

second, with 35 per cent. This area received over half of the total annual typhoons suffered by China.

3. In Fukien and Kwangtung typhoons were most frequent in July, August, and September. One-fourth or one-fifth of the total number of typhoons for a whole year occurred during these three months.

4. Hainan Island suffered one-fifth of its total typhoons in July, making that the month with the greatest frequency of typhoons.

Table 6 shows how typhoons behaved after hitting Formosa. From this information we may make the following five points:

1. In May Formosa had only one typhoon, which never reached the mainland of China.

2. In June one-third of the typhoons which reached Formosa tended to move to Fukien afterwards, the areas south and north of Fukien escaping any encounter with them.

3. More than 80 per cent of the typhoons which blew over Formosa in July and August proceeded to attack the continent. Most of them, however, rushed upon Fukien and the region north of it.

4. Over 80 per cent of the typhoons in September traveled from Formosa to China, but their main target was Fukien.

5. In October typhoons behaved as they had in June.

Table 6

NUMBER OF TYPHOONS THAT REACHED THE MAINLAND OF CHINA AFTER BLOWING OVER FORMOSA[1]

Destination of Typhoons leaving Formosa:	May	June	July	Aug.	Sept.	Oct.	Nov.	Whole Year
Chekiang and Area North of It	-	-	2	5	-	-	-	7
Fukien	-	2	22	25	15	1	-	65
Kwangtung	-	-	-	4	-	-	-	4
Typhoons that Disappeared in the Sea	1	5	1	6	6	2	1	22
Total No. of Typhoons that Blew Over Formosa	1	7	35	36	25	3	1	98

[1]Computed from the data of the weather bureau of Formosa and Shih, *op. cit.*

2. Typhoons and Rainfall Patterns

From Father Gherzi's map of annual precipitation in China it can be noted that in southern China there are three areas of heavy rainfall along the southeastern coast: one in Chekiang, another in northeastern Kwangtung, and a third around Pakhoi (Figure 4). According to Alfred J. Henry, the orographic influence does not seem to dominate in these cases, because in Kweichow, where there are great mountains, the quantity of rain received is well below that of the three zones mentioned above. The abundant rainfall in the three regions mentioned seems to be due to the effect of typhoons.[1]

Yet a preliminary examination of the statistics concerning the frequency of rainfall and typhoons reveals no apparent correlation. Using data from Hong Kong, during the sixty years under consideration 35 typhoons occurred in years of less than average rainfall and 35 in years having more than average rainfall. The average rainfall of Hong Kong is 85.1 inches. The wettest and the driest years (1889 with nearly 120 inches of rain and 1895 with less than 46 inches) each had one typhoon. The year with the rainfall nearest the average had two typhoons. Four typhoons occurred in each of the following years, all of which were above average in rainfall: 1929, with 107 inches of rain; 1894, with 104 inches; and 1893, with 100 inches. On the other hand, three typhoons occurred in these years, all of which were below

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[1]Alfred J. Henry, "Father E. Gherzi, S. J., on a 'Study of Rainfall of China,'" Monthly Weather Review (January 1929), pp. 12-17 .

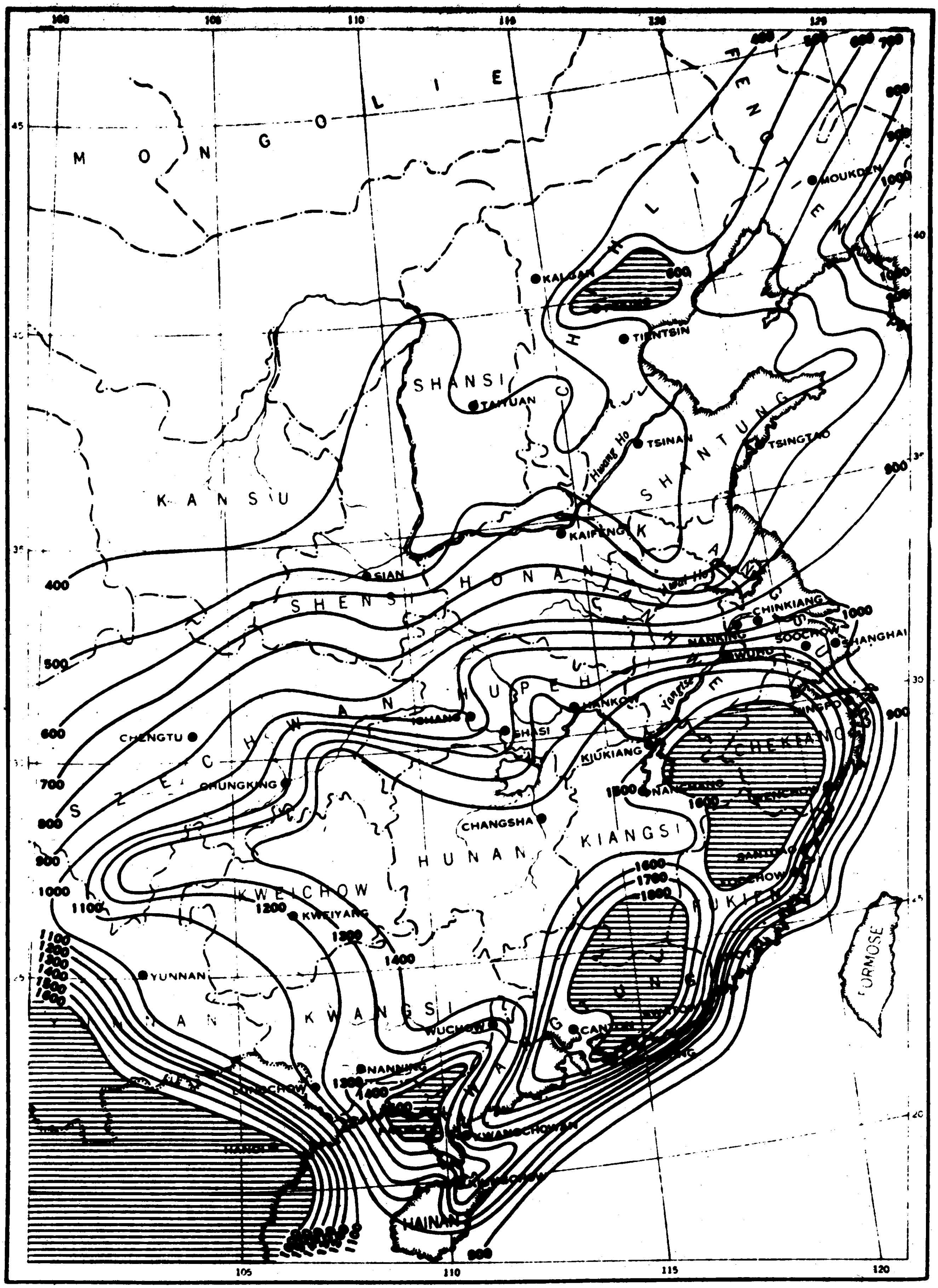

Figure 4. Annual Precipitation of China. (After Gherzi)

average in rainfall: 1906, with 78 inches of rain; 1896, with 73 inches; and 1887, with 66 inches.[1]

It appears, therefore, that on an average the total annual rainfall was largely independent of typhoon occurrences in Hong Kong or southern China. This would indicate that several typhoons in any one year do not necessarily mean that the total amount of rainfall for that year will be excessive.

Although the wide variations in the amount of annual rainfall are sufficient to mask any correlation between it and typhoon occurrences, further investigation of monthly data shows that such a correlation does exist. The data for average monthly rainfall in Hong Kong reveals one maximum in June and July (Figure 5).

Using the five-day means of rainfall rather than the monthly means, however, we notice a peculiar double maximum, one peak occurring in the middle of June, the other in the second half of July, with a marked subsidiary minimum between them (Figure 6). (Rainfall in the period from July 10 to July 14 is considerably less than that in the succeeding five-day period, July 15 to July 19.) This significant secondary minimum in the rainfall of Hong Kong usually occurs between the fifth and tenth of July. The mean rainfall for the interval from the fifth to the tenth of July is 50.5 mm., compared with 65.5 mm. for the period from the twentieth to the thirtieth of June, and 77 mm. for

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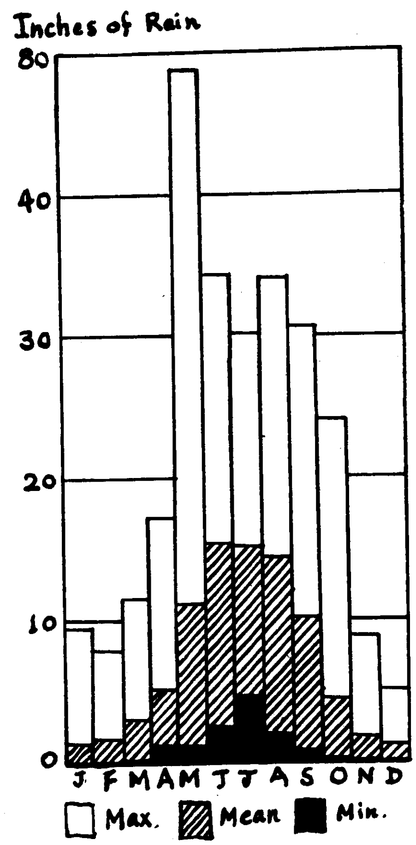
[1] L. Starbuck, A Statistical Survey of Typhoons and Tropical Depressions in the Western Pacific and China Sea Area, 1884 to 1947 (Hong Kong), Royal Observatory of Hong Kong, 1951, p. 9.



<u>Figure 5</u>. Monthly Mean, Absolute Maximum and Absolute Minimum Amounts of Hong Kong Rainfall (55-year mean, 1884-1938) (From Starbuck)

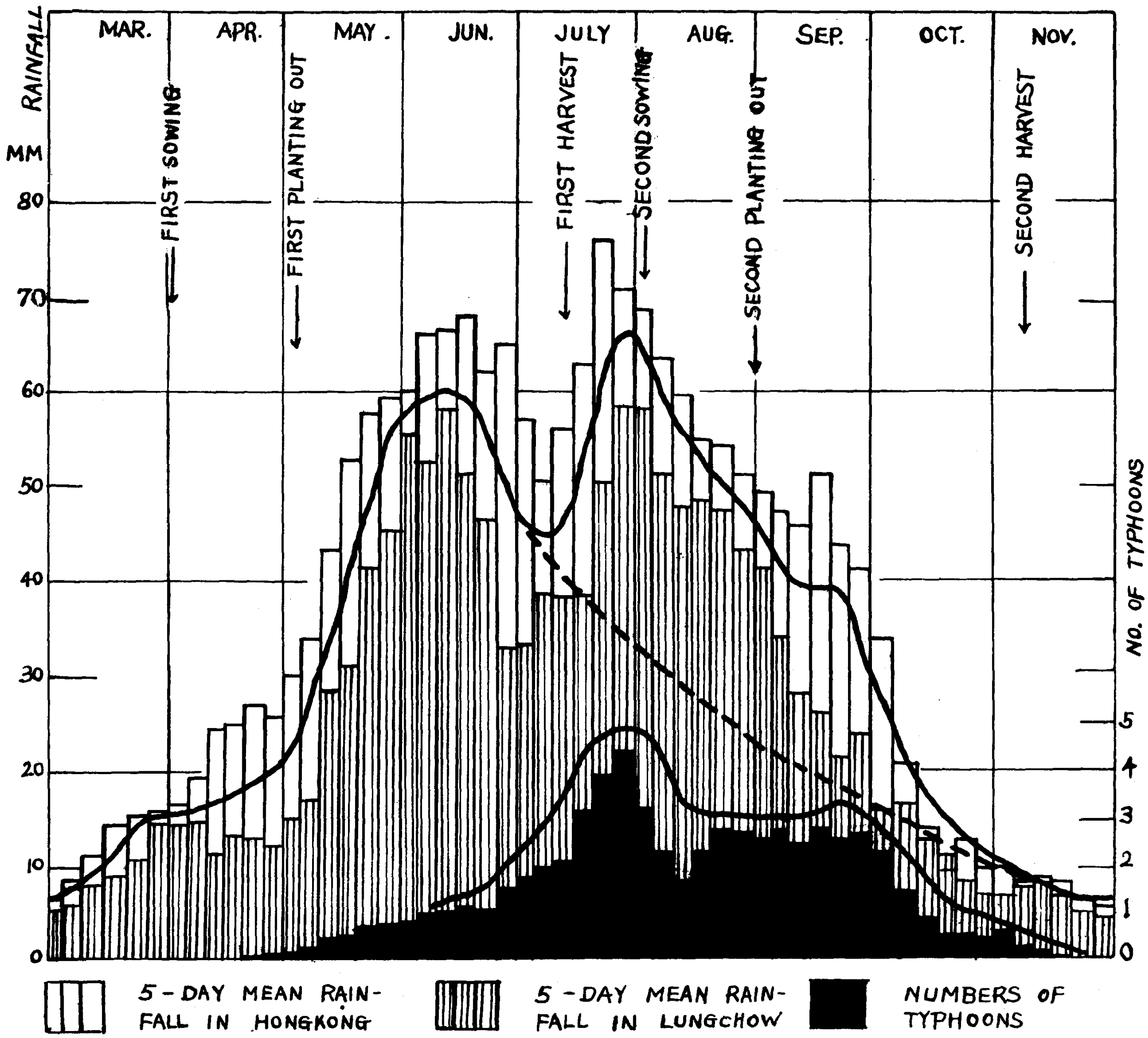


Figure 6. 5 Day Means of Rainfall and Typhoon Frequencies in Southern China. (From Ramage)

the twentieth to the twenty-fifth of July. This apparent anomally in the middle of the wet season marks the transition between two different types of maxima of rainfall in Hong Kong.

In a recent paper Mr. C. S. Ramage pointed out that this secondary minimum occurs not only in Hong Kong, which is typical of eastern South China, but also elsewhere in southern China. For instance, Lungchow, which is typical of western South China, has an even more marked secondary summer minimum of rainfall than Hong Kong.[1] (See Figure 6.)

The five-day mean frequencies of typhoons affecting southern China, illustrated by the same diagram, show a marked correlation with the rainfall curve, subsidiary maxima and minima being generally coincident. It appears very probable, therefore, that the second maximum of the rainfall curve is due to an added contribution of rain resulting from typhoons.

It is significant also that of the 17 years when no typhoons affected Hong Kong, 14 were proportionally deficient in rainfall for the typhoon months (July to November); while of the seven years that had either three or four typhoons each, six had a proportionately high rainfall for the typhoon months.

The smoothed curve of five-day means (Figure 6) was extended from the first maximum in June, interpolating the normal decrease in the

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[1] C. S. Ramage, "Variation of Rainfall Over South China Through the Wet Season," Bulletin of the American Meteorological Society, Vol. 33 (1952), p. 309.

second half of that month and the first half of July to meet the curve in the latter half of November. By subtraction, the rainfall attributable to typhoons (shown by the dot-dash curve) amounts to about 20 per cent of the annual total. If this indeed be the case, a solitary consoling factor emerges from southern China's susceptibility to typhoon visitations: water supply in southern China, especially in Hong Kong, would be a much greater problem.

The wet season of southeastern China may be conveniently divided into six periods, each corresponding to the Chinese farming activities (Figure 6).[1]

3. Typhoons in Hong Kong

The Observatory of Hong Kong was founded in 1883, and from 1884 onward complete meteorological observation has been recorded continuously, except during the war years 1942-1945 for which no records are available. It is known, however, that no severe typhoons occurred during these years. The following data on pressure, wind, and weather in connection with typhoons in Hong Kong are summarized from the Observatory's report.[2]

Pressure

Typical barograms illustrating the fall and rise of atmospheric pressure during the passage of typhoons at distances of 5, 35, 70, and 100 miles from Hong Kong are shown in Figure 7. The curves vary widely.

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[1] Ibid.
[2] G. S. P. Heywood, Hong Kong Typhoons, 1950; L. Starbuck, op. cit.

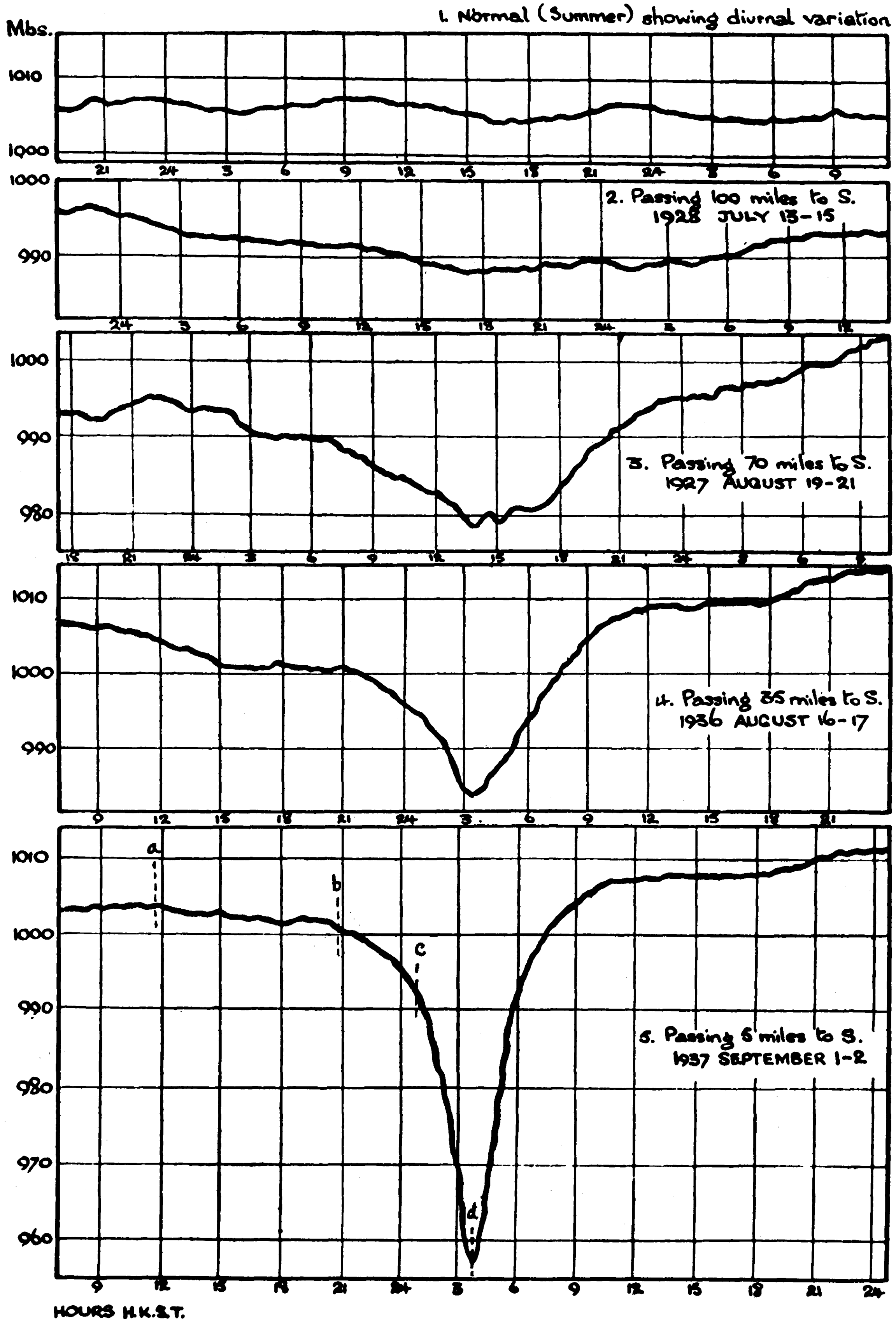

Figure 7. Pressure in Hong Kong. (From Starbuck)

A typhoon of moderate intensity passing at a considerable distance may cause only a gradual fall and rise in the barometer (curve 1). On the other hand, a well-developed typhoon, whose center passes close to the observer, is characterized by a sharp V on the barogram (curve 5). Three stages may be discerned in the fall of the barometer while a typhoon is approaching; the sequence is illustrated in curve 5. In the first stage (a-b) the fall is so gradual that the normal twice-daily variation of atmospheric pressure is still evident. Perhaps six hours before the passage of the center, the barometer begins to fall more rapidly, and the diurnal variation of pressure is obscured (b-c). Finally, a very steep fall sets in and continues until the center passes (c-d), to be followed by an equally steep rise. This sharp V on the barogram corresponds with the core of violent winds around the center of the typhoon. It is noteworthy that on the average the rise in pressure after the passage of the center is more rapid than the preceding fall, and the final reading of the barometer after the storm has ended is some 3 mb higher than before it commenced.

Wind

Since the typhoons in the northern hemisphere rotate in an anticlock-wise direction around the center, we see that when a typhoon is approaching Hong Kong from ESE (the usual track) the wind sets in from the north or northeast, at first only lightly, but gradually increasing in speed. Should Hong Kong lie to the right of the track so that the center passes south of the island, the wind direction will veer from northeast through east to southeast or south. On the other hand, if the center passes to the north or northeast of Hong Kong, leaving it on the left of the track, the wind will back through northwest to west or southwest.. The change in wind direction occurs at the height of the storm when the center is nearest, and thereafter the wind begins to moderate. There is a third possibility--the calm center may pass directly over the observer, in which case the wind, after reaching its maximum violence from one direction, suddenly dies down almost to a calm, only to set in again with equal force from the opposite direction. The calm center has passed over Hong Kong only once since records were commenced.

It is an ominous sign when a northerly wind increases steadily in force without any tendency to veer or back in direction, for this means that the center of the storm is moving directly towards Hong Kong. The highest hourly wind speed ever recorded was 69 knots during the typhoon of July 29, 1896.

The wind reaches gale force when it attains a mean speed of 34 knots (39 m.p.h., or force 8 on the Beaufort Scale). The duration of typhoon gales is quite variable, depending on the speed at which the storm is traveling and also on the extent of the gale area and the distance at which the center passes the observer. The longest gale lasted for 27 hours, from October 4 to 6, 1894; it was caused by a rather slow-moving typhoon which approached from the southeast, recurved around Hong Kong, and moved away to the northeast after lingering unpleasantly close for an unusually long time. On several occasions the gale has lasted for only one hour; such a gale results from tropical storms of small intensity or from storms passing at a considerable distance from Hong Kong. The average duration of gales is seven hours.

The sequence of wind directions during each gale is shown diagrammatically in Figure 8. Of the 74 typhoons that occurred in the 62-year period, 62 set in first from the northeast quadrant and twelve veered in direction during the passage of the storm.

Weather

It is a striking fact that a short spell of fine sunny weather is almost always experienced in Hong Kong when an approaching typhoon is entering the China Sea. The sky does not usually cloud over until some 18 to 36 hours before the passage of the center, depending on the size and speed of advance of the typhoon. The records show that fine weather occurred in Hong Kong within 48 hours of the passage of 56 out of the 73 typhoons for which reliable observations are available. Of the 17 typhoons which were not preceded by a fine spell, several were unusually slow moving and others did not approach from the southeast. This characteristic good weather gave rise to the local saying that a typhoon may be expected when the twin heads of Lantau peak are visible. The clear weather is probably due to the fact that the trade wind airstream aloft, after overtaking the typhoon on its northern side, tends to diverge at some distance to the northwest of the center, with the result that the air subsides and the clouds are dissipated.

The heaviest rainfall ever recorded in one hour during a typhoon was 54.6 mm. (2.15 inches), which fell in the hour following the passage

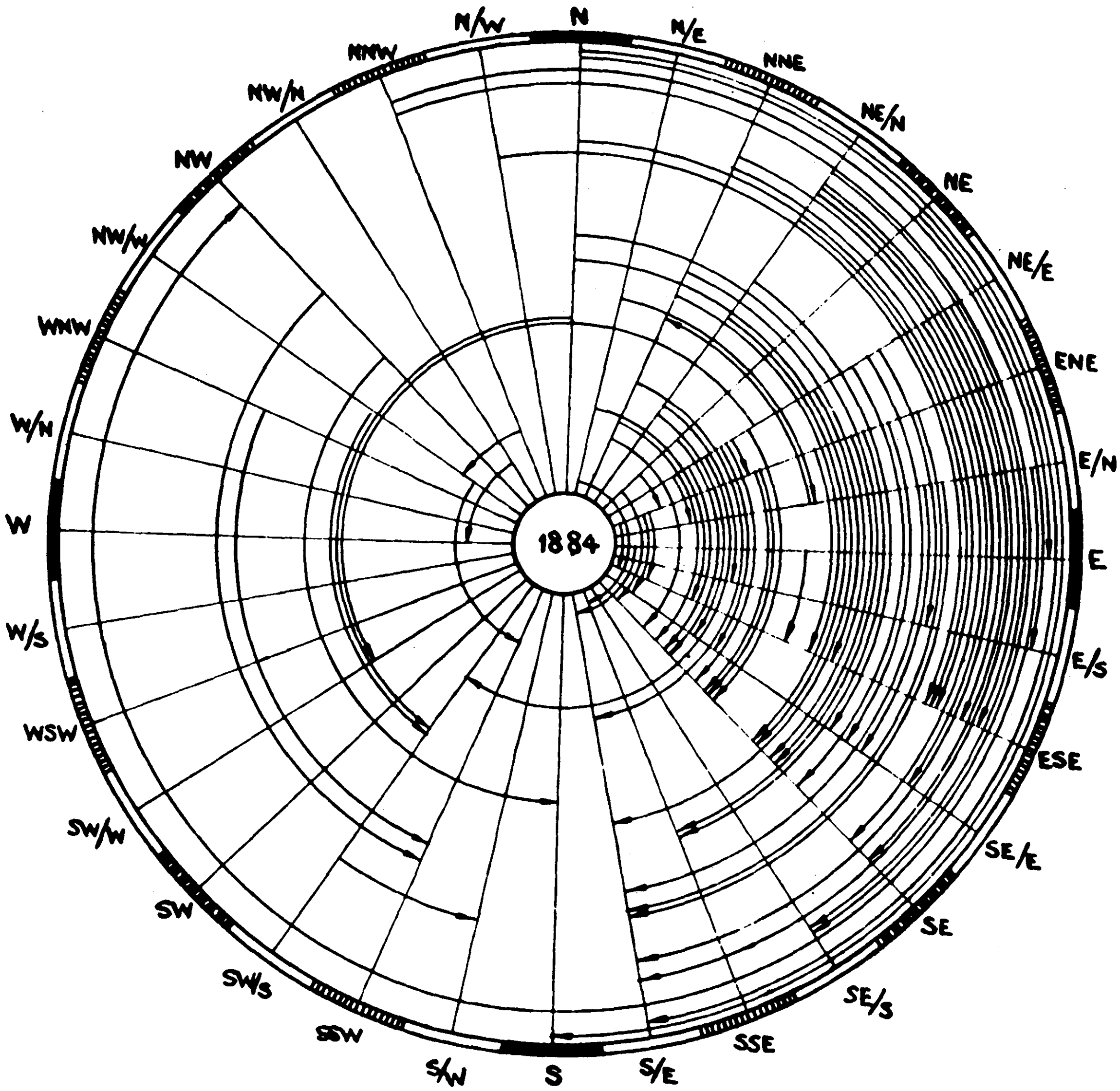

Figure 8. Sequences of wind direction in Hong Kong. 1884-1941, 1946-1947, Arranged Chronologically from the center. (From Starbuck)

of the center during the typhoon of September 2, 1937. The greatest total rainfall ever recorded in 24 hours during a typhoon was 279.7 mm. (11.01 inches) on the fifth and sixth of October, 1894); this typhoon was the slow moving one already mentioned as producing the most prolonged gale in Hong Kong. The "driest" typhoon, which occurred on October 12 and 13, 1890, produced a total of only 0.5 mm. (0.2 inches) of rain. However, it traveled rapidly and passed well to the south of Hong Kong.

It is of interest to note that very heavy rainfall in Hong Kong may have no connection whatever with a typhoon. The heaviest rain on record occurred on July 19, 1926, when 100.7 mm. (3.97 inches) fell in one hour and 534.0 mm. (21.03 inches) fell in 24 hours during a prolonged and intense thunderstorm.

IV. TYPHOONS ON FORMOSA

1. Monthly Distribution of Typhoons and their Relation to the Rainfall Type

In a period of 51 years, 1895 to 1945 inclusive, 98 typhoons struck Formosa causing varying degrees of damage. The distribution of these typhoons, according to months, is as follows:

Table 7[1]

Month:	May	June	July	August	Sept.	Oct.	Nov.	Whole Year
Number of Typhoons:	1	7	25	36	25	3	1	98

The earliest month in which a typhoon visited Formosa was May and the latest was November. For the five months from December to April, there were no typhoons. About 86 per cent of Formosa typhoons were concentrated in July, August, and September, one-third of the typhoons occurring in August. One-fourth of the typhoons came in July and September, while another fourth occurred in the remaining months.

If we use the five-day means of rainfall for Formosa, as we did with southeastern China, we notice peculiar double maxima, one peak occurring in the middle of June, the other in the second half of July, with a marked subsidiary minimum between them (Figure 9). This significant secondary minimum in the rainfall of Formosa usually occurs

[1] Computed from the Report of the Weather Bureau of Formosa and Shih, *op. cit.*

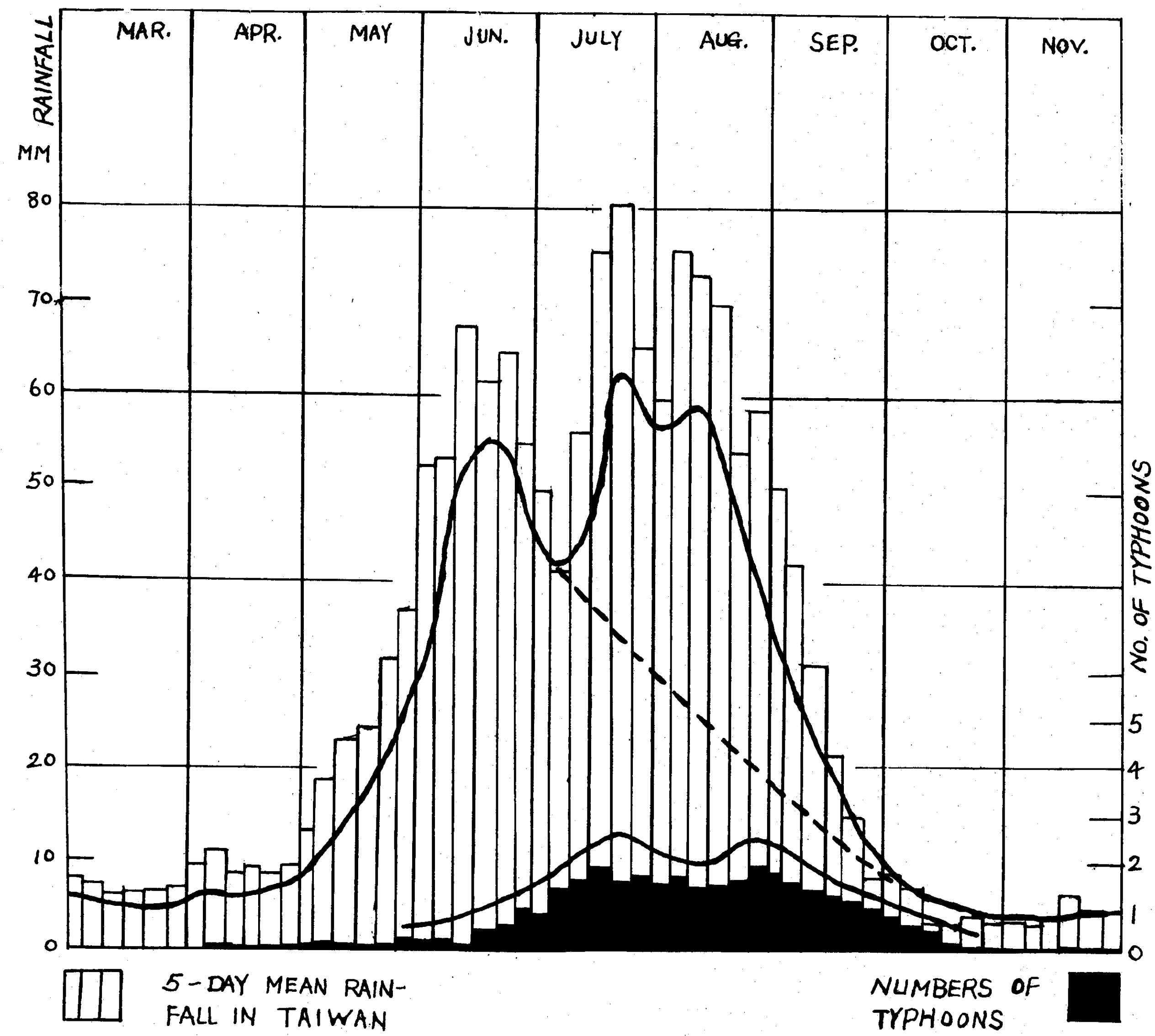

Figure 9. 5 Day Means of Rainfall and Typhoon Frequencies in Formosa (After Ramage)

at the beginning of July. The mean rainfall for this minimum is about 40 mm., as compared with 55 mm. for June 25 to 30, and 80 mm. for July 20 to 25. This minimum rainfall in the middle of the wet season marks the transition between two different types of maxima of rainfall in Formosa.

The five-day mean frequencies of typhoons affecting Formosa, shown on the same diagram, correlate closely with the rainfall curve, subsidiary maxima and minima being generally coincident.

The smoothed curve of five-day means (Figure 9) was extended from the first maximum in June, interpolating the normal decrease in the second half of that month and the first half of July through to meet the curve in the latter half of November. It appears very probable that the second maximum of the rainfall curve is due to additional rain resulting from typhoons.

2. The Destructiveness of Typhoons in Formosa

The typhoon that visited the southernmost part of Formosa on August 26 and 27, 1911 was one of the most violent and destructive. The barometer at Kao-hsiung fell to 702.9 mm., the lowest ever registered. On this occasion the greatest wind velocity recorded was 49.2 meters per second; at this point the cups of the anemometer were blown away making further observations impossible. The strength of the wind at that time could be judged from the force with which broken pieces of tile were driven like shrapnel into wooden boards and trunks of trees. It was estimated that the wind velocity reached nearly 70 meters per second, or 156 miles per hour. During the progress of the typhoon a velocity of 54.5 mm. per second, or 122 miles per hour, was reached at Formosa. This storm inflicted terrible damage in the southern part of the island taking a toll of 305 human lives, with 378 persons wounded, 190 missing, and more than 30,000 houses destroyed.[1]

As an example, when the typhoon reached the district of Taitung the pressure fell to a low of 726.3 mm., and the velocity of the wind was registered at 46.3 meters per second, or 104 miles per hour, causing considerable damage to that district. However, when the storm appeared on the west coast after crossing the central mountain range, its strength had greatly decreased and its influence was scarcely felt in that part of the island. In Formosa the barometer fell to 745.6 mm., but the wind velocity reached only 18.5 meters per second or 40 miles per hour.[2]

The most violent and destructive typhoon suffered by Formosa struck the island on September 25-26, 1946. The pressure of the center fell to 703 mm. as the storm approached the east coast of the island. The average maximum wind velocity was 40.3 meters per second, and the extreme maximum recorded was 55 meters per second. This great storm destroyed 373,748 houses, damaged 564,263 hectares of crops and forest, and 28,448 animals were reported lost, 154 persons killed, and 618 persons injured.[3]

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[1] The Climate, Typhoons and Earthquakes of the Island of Formosa, Taihokn Meteorology Observatory, 1914.

[2] Ibid.

[3] Report of the weather bureau of Formosa, 1946.

3. Typhoons and Rice Cultivation

Each year during the 24-year period of 1919 to 1942 the area of paddy field and dry rice land damaged by natural causes amounted to more than 80,317 hectares. Typhoons damaged 55,676 hectares of land, and drought was the second most destructive factor[1] (Table 8). The western plains experienced the greatest devastation, particularly in the area around Tainan, while the eastern part suffered less damage, mainly because there was less farm land in the eatern section (Table 9).

From Table 10 we notice that Formosa produced much less native rice than Horai rice, which was introduced from Japan. The Horai rice was usually planted in the more fertile fields and required a large quantity of fertilizer. However, the amount of native rice harvested was more stable than that of the Horai rice, largely because in the first cropping of the Horai rice the crops were damaged by diseases, and in the second cropping the rice suffered from typhoons.

Table 10

A COMPARISON OF THE HARVEST OF THE FIRST AND SECOND CROPPINGS OF NATIVE RICE AND HORAI RICE IN FORMOSA[2]
(1924-1943)

	Native Rice		Horai Rice	
	First Cropping	Second Cropping	First Cropping	Second Cropping
Average production of rice in hectolitres per hectare	24.18	21.39	27.34	23.80

[1] *Agricultural Yearbook*, 1946, Department of Agriculture and Forests, Governor General's Office of Taiwan.

[2] *Agriculture Report*, Agricultural Experimental Station, Taiwan, Vol. 5, 1947.

Table 8

CAUSES OF DAMAGE TO RICE CROPS IN FORMOSA AND AVERAGE AREA DEVASTATED PER YEAR (1919-1942)[1]

	Typhoons	Drought	Flood	Disease	Total
PADDY RICE					
Damage in Hectares	55,676	11,843	12,034	764	80,317
Per Cent of Area	69.2	14.7	15.0	1.0	100
Hectolitres Lost	180,712	104,927	51,334	5,775	-
Per Cent of Rice Lost	52.6	30.6	16.2	-	-
DRY RICE					
Damage in Hectares	5,238	1,469	415	5	7,127
Per Cent of Area	72.5	20.6	5.9	-	-
Hectolitres Lost	13,725	10,251	1,212	26	-
Per Cent of Rice Lost	53.8	40.5	4.8	-	-

[1] Ibid.

Table 9

THE DAMAGED AREA IN DIFFERENT COUNTIES[1]
(1919-1942)

	Paddy Rice			
	Damage in Hectares	Per cent of Area	Hectolitres Lost	Per cent Lost
Hsinchu	20,503	22.2	73,062	21.3
Taichung	17,893	33.2	71,957	21.0
Tainan	17,653	21.9	89,801	26.2
Taipeh	13,392	16.7	52,710	15.5
Kaohsiung	8,085	10.1	41,573	12.1
Hualien	1,712	2.1	6,452	1.9
Taitung	1,193	1.5	7,642	2.2
	Dry Rice			
Hsinchu				
Taichung	341	4.8		
Tainan	4,260	59.7	13,569	53.6
Taipeh				
Kaohsiung	2,316	32.5	9,613	31.8
Hualien				
Taitung				

[1] *Ibid.*

If we compare the length of the growing periods of native rice and Horai rice, we notice that the second crop of Horai rice matures earlier, as shown in the following table:

Table 11

COMPARISON OF THE NUMBER OF GROWING DAYS REQUIRED BY NATIVE RICE AND HORAI RICE (1935-1939)[1]

		In Seed Beds	Seed Beds to Sprouting	Sprouting to Maturity	Total Growing Days
Native Rice	1st Cropping	44.1	84.2	37.4	163.0
	2nd Cropping	32.5	75.2	34.5	142.5
Horai Rice	1st Cropping	34.7	74.4	38.9	148.0
	2nd Cropping	16.2	58.6	42.3	117.1

In the years 1933 to 1940 the second cropping of Horai rice usually sprouted in late September in northern and central Formosa, and in mid-September in the southern part. As mentioned before, within a period of 51 years (1895-1945 inclusive) there occurred 98 typhoons, most of which struck in July, August, and September. One quarter of the total number of typhoons occurred in September, and the fact that September has frequent typhoons is extremely important because the second cropping of Horai rice sprouts in that month.

The amount of damage done to the rice crops by typhoons is closely related to the stage of growth of the rice at the time. Typhoons do only slight harm to rice in the seed bed stage, and rice in the mature

[1] *Ibid.*

stage does not suffer greatly from typhoons because it is strong enough to resist such storms. The most serious damage results during the sprouting stage, for at this point the rice is most adversely affected by typhoons.

Figure 10, which was prepared by an agronomist, illustrates this point.[1] If a typhoon were to strike when the rice was just in the sprouting stage, 80 per cent of the crop would be destroyed, but if the typhoon struck six days before the sprouting time, 25 per cent of the crop would be destroyed. Moreover, if it struck two days after the rice had sprouted, only 6 per cent of the crop would be destroyed. Thus rice suffers the most damage during the sprouting stage. In order to minimize the disastrous effects of typhoons, it appears necessary to shift the time of planting the rice.

The following suggestions are offered in the interest of avoiding typhoon damage:

1. The first crop of both native rice and Horai rice should be started earlier so that the crop will mature before the end of June, and the second crop should be planted later so that its period of maturation will fall in October. In this way the rice would not be in its most vulnerable stage during the main typhoon season, from June to September.

2. However, several problems arise. While it is easily possible for the first cropping of both native rice and Horai rice to mature

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[1] <u>Ibid</u>.

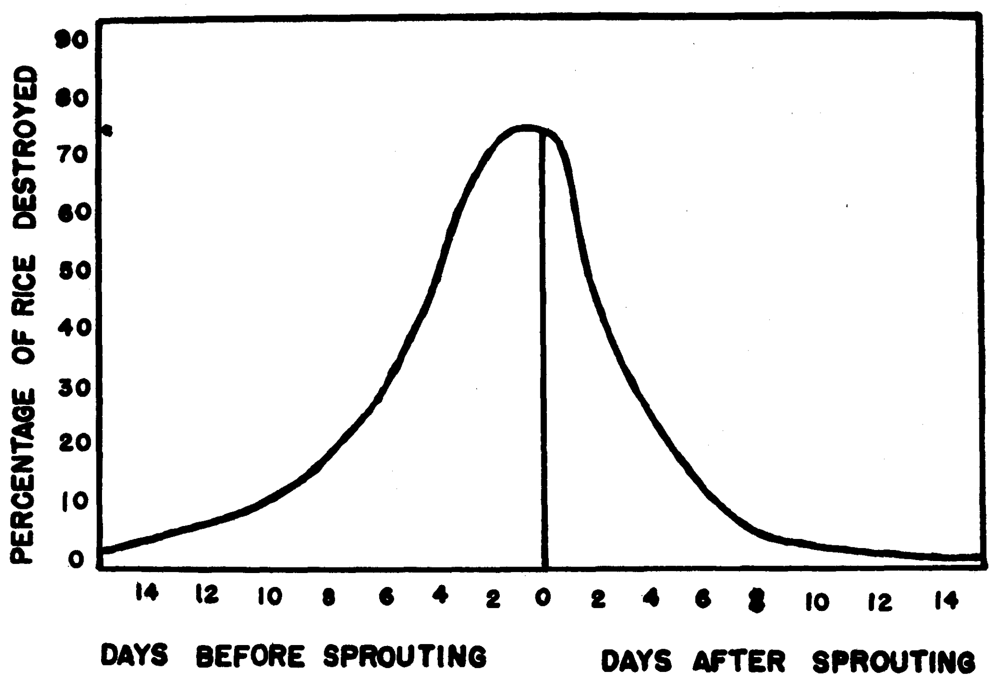

Figure 10. The Possible Damage to Rice Crops by Typhoons

before the end of June, both would be more subject to disease if grown earlier, Horai rice being weaker in this respect than the native variety. Therefore, a new kind of rice more capable of resisting disease should be developed.

3. To escape the September typhoons, the second crop of rice must sprout after the beginning of October. This program can be followed with the native rice, but it would be difficult to delay the sprouting of Horai rice. However, some agricultural method might be applied to take care of this problem. Another way of solving the difficulty would be to concentrate on native rice during the second cropping season, decreasing the amount of Horai rice.

4. It appears then that the safest way to have good harvests in Formosa is to encourage Horai rice for the first cropping and native rice for the second cropping.

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