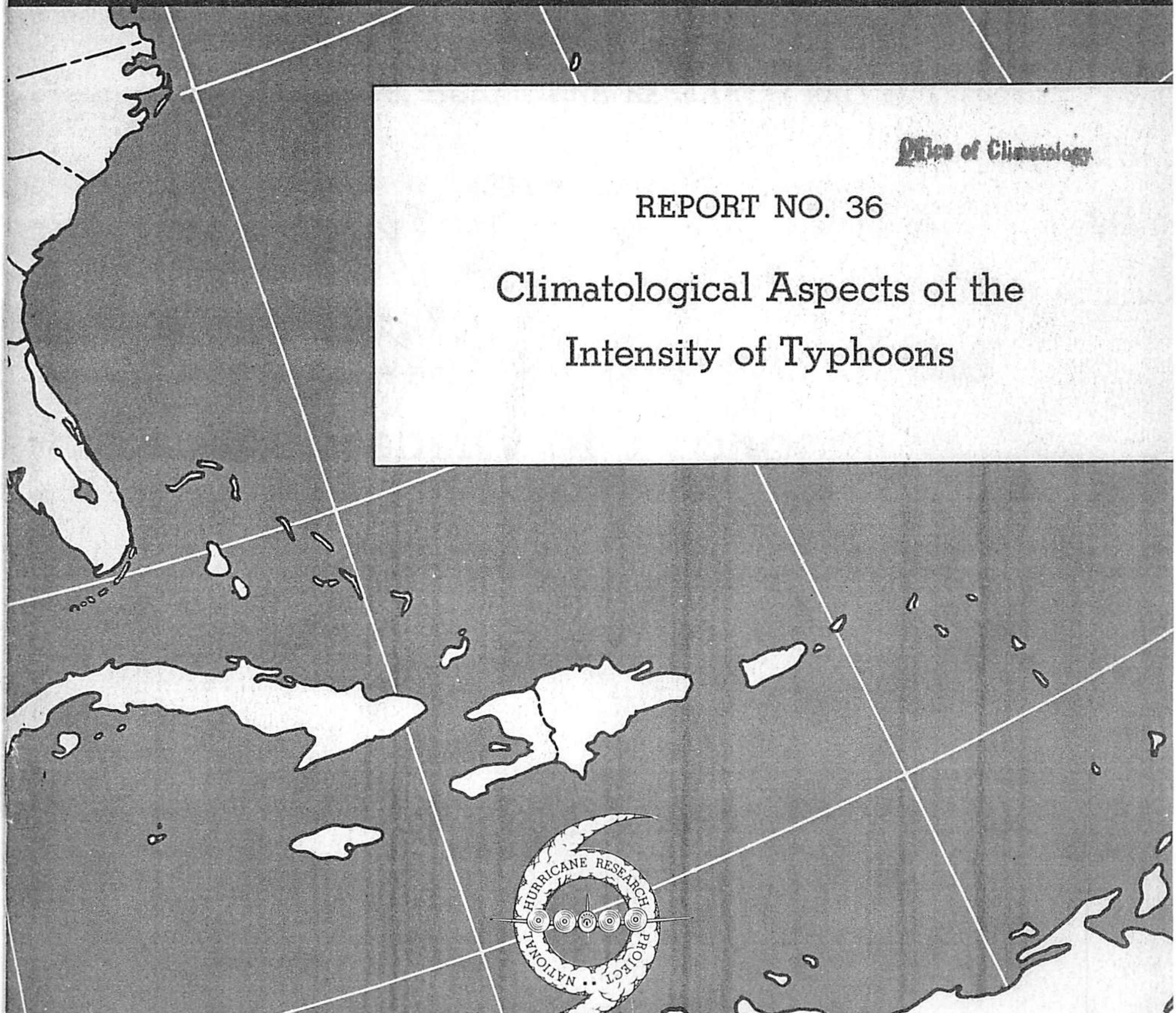
NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 36

Climatological Aspects of the Intensity of Typhoons



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Climatological Aspects of the Intensity of Typhoons

by

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NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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CLIMATOLOGICAL ASPECTS OF THE INTENSITY OF TYPHOONS

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ABSTRACT

Some aspects of the intensity of typhoons have been investigated by utilizing central pressure data observed during the period 1950-1957. Interannual seasonal changes in the frequency of storms of different intensities are examined and compared with statistics relating to typhoons of all intensities covering a much longer period. Geographical aspects of typhoon formation and intensity have been investigated by plotting the formation points and the points of minimum pressure of individual typhoons and by preparing maps depicting the frequency of typhoons of different intensities.

1. INTRODUCTION

The intensity of tropical cyclones forming in the same geographical area and moving along similar paths varies greatly from year to year and also between individual cases during the same season. Some storms show a great deal of organization and persist for long periods when the central pressure is only slightly below 1000 mb. and winds are barely of hurricane force. Other storms in the same area and season occasionally deepen to central pressures below 900 mb. and the winds attain values much in excess of hurricane force. Very little is known about the factors which govern the intensity of tropical cyclones and, in fact, not much information is available on the seasonal, geographical or interannual variability or intensity. Until the advent of aircraft reconnaissance, quantitative knowledge of the intensity was lacking during most or even all of the life of an individual tropical storm. Therefore, it has been impossible to build up climatological information which would permit an evaluation of the geographical and seasonal variation of the intensity of tropical cyclones. In fact, it has been only during the past few years that some measure of the storm intensity, either maximum winds or central pressure, has been shown on the tracks of individual tropical storms.

The reconnaissance of tropical cyclones in the western North Atlantic and central and western North Pacific areas began in 1943 and the completeness of reconnaissance coverage has steadily increased. During the past few years practically all of the known tropical cyclones in these areas have been reconnoitred and it is now rare when a day passes without at least one aircraft investigation of every known tropical cyclone. Therefore, in the Atlantic and North Pacific areas we ordinarily have a measure of the intensity of a tropical cyclone from one day to the next and such information is available for nearly all storms within recent years. Data of this type have been used in this investigation in an effort to provide some climatological information on the intensity of tropical cyclones.

The intensity of a tropical cyclone is normally judged either in terms of the central pressure or the maximum observed wind speeds, but, as shown by empirical studies [1,2], there is a high degree of correlation between these two quantities. The maximum wind speed at the surface is perhaps the most desirable measure of the intensity from the viewpoint of the forecaster, but this quantity cannot be determined in an objective and reliable manner from the reconnaissance aircraft. Many of the flights are made at levels of 10,000 ft. or higher and the estimates of maximum surface wind speed must be based on the appearance of the ocean surface as viewed in very limited areas of the storm. Therefore, the maximum surface winds reported in the reconnaissance observation may be somewhat less than those present in some of the obscured areas. There is the further difficulty that the wind speed estimates based on state of sea observations are rather crude at extreme speeds (cf. [3]). In recent years flight level winds of a high degree of accuracy have been provided by the automatic navigation system, APN-82, carried in the Air Force reconnaissance aircraft; however, there is no known objective means of deriving surface wind speeds from the flight level values, which are normally available for either the 700-mb. or 500-mb. level. In contrast, the central pressure, which is ordinarily determined by dropsonde observations from the aircraft, is a quantitative measure of the storm intensity. Errors in the dropsonde pressures are not likely to exceed a few millibars [4] and for the purposes of this study such errors are negligible. In view of the considerations indicated above, it was decided that intensity would be expressed solely in terms of the central pressure of the storm.

2. DATA

This investigation will be confined to a study of intensity of typhoons in the western Pacific and China Sea areas during the period 1950-1957. Even with the relatively high frequency of occurrence of tropical cyclones in these areas the available period of record is not long enough so that stable climatological statistics can be expected. All conclusions concerning frequencies and variabilities must be considered as tentative ones and should be checked as records for longer periods become available. Obviously, similar statistics for the Atlantic area based on the available sample of reconnaissance observations would be even more questionable in view of the smaller number of tropical cyclones that occur in this area in comparison with the Pacific. The marked difference in tropical cyclone frequency in the two areas is evident from the fact that our sample size for an 8-year period for the Pacific is more than half as large as the 55-year sample used by Dunn [5] in a study of the areas of hurricane development in the Atlantic.

The data used in this study were taken from two primary sources. The Air Force Typhoon Post Analysis Board Consolidated Reports were available for most individual typhoons which occurred in the years 1951 to 1954. These provided detailed storm track information as well as central pressure and maximum wind data from each reconnaissance flight. The second source was the "Trajectories of Tropical Cyclones" published annually by the Japanese Meteorological Agency. These charts, which are available for the period 1940-1957, provided the tracks of all tropical cyclones and listed a value for the central pressure once per day.

For the years 1951-1954, the daily central pressure value given on the Japanese tracks could be compared against reconnaissance information listed in the Air Force reports of the individual typhoons. Differences were ordinarily small and it was quite apparent that the central pressure values shown in the Japanese tracks were based largely on the dropsonde observations. Since the two sets of data agreed so closely, it is not felt that the results were influenced to any appreciable extent by the fact that the detailed reconnaissance data for the later years (1955-1957) were not available for this study.

The information from the Japanese trajectory charts was available for the decade 1940-1949 but, since dropsonde observations were completely lacking in the early part of this period and rather infrequent in the latter portion, it was felt that the accuracy of the listed central pressures would be much poorer than in the later years. A check of the central pressures during the latter part of this decade indicated that the listed values were, on the average, appreciably higher than those listed in the years subsequent to 1950. We, therefore, decided to use none of data earlier than 1950 in this study.

The geographical limits for the area considered in this report are 160° to 115° E. longitude and 5° to 35° N. latitude. The northern border is arbitrary but most tropical storms tend to take on extratropical characteristics in the vicinity of 35° N. Only a small percentage of the storms formed east or west of the stated boundaries and none formed south of 5° N.

3. CLASSIFICATION OF TROPICAL CYCLONES

The tropical cyclones considered in this study were divided into three main categories based on the minimum value of central pressure observed during the life of the storm. Limits for the categories are: I - all storms with central pressures less than 990 mb., II - storms with central pressures equal to or less than 950 mb., and III - storms with central pressures equal to or less than 920 mb. It should be noted that these categories are overlapping. For example, storms which fall in category III are also included in category I. For convenience, the storms in category I will be referred to simply as typhoons, those in category II as deep typhoons, and those in category III as very deep typhoons. In addition to these three main categories, some statistics will be presented for the weaker storms in which the central pressure did not fall below 990. mb.

The 990 mb. value has been used as a rough separation between typhoons and the weaker storms[1], since empirical studies associating central pressure and maximum surface winds [2] have indicated that typhoon-force winds are present in most cases when the central pressure falls below 990 mb. In making such

[1]Tropical cyclones in the western North Pacific are classified as "typhoons" if the maximum speeds exceed 63 knots. Tropical cyclones with maximum speeds in the range from about 35 knots to 63 knots are referred to as "tropical storms" and organized cyclonic circulations with speeds less than 35 knots are referred to as "tropical disturbances."

a division we run the risk of including some cases when the winds failed to attain typhoon force and of excluding other cases when winds were of typhoon force. An examination of the minimum pressure and estimated maximum wind speed data for individual storms for the years 1951-1954 showed that three cases with winds of 64 knots or greater were excluded by this classification from a total of 69 cases and four cases were included with winds less than typhoon force. Of course, some of the weaker cases may have had typhoon-force winds over very limited areas for short periods of time which were not discovered by the reconnaissance aircraft. Later, some statistics will be presented to show the number of storms of lesser intensity which were excluded from our sample. Also, some of the difficulties which arise in classifying and treating these weaker cases will be discussed.

The above discussion suggests that a very large portion of the typhoons can be isolated simply by determining whether the minimum central pressure fell below 990 mb. The point of separation between typhoons and tropical storms, as defined by the wind speed value of 64 knots, appears to have some physical justification in terms of the organization of the storms. It has been found that as the wind speed develops to typhoon force - and the central pressure approaches 990 mb. - the wind field surrounding the storm usually becomes more symmetrical, the radar bands tend to take on the characteristic spiral form, and the eye appears as a well-defined feature. This transition, which will be assumed to occur when the central pressure falls to 990 mb., will be viewed as the point of typhoon formation.[2] It is felt that this is a realistic point of view since tropical cyclones may persist as poorly organized features for several days with central pressures near 1000 mb. and then take on typhoon characteristics as the central pressure falls. Of course, in many cases the weaker storms never attain typhoon intensity.

The further classification of typhoons based on the 950 mb. and 920 mb. pressure values is much more arbitrary than the 990 mb. value which provides at least a rough separation between tropical storms and typhoons. The maximum wind speeds and the area covered by typhoon-force winds normally show gradual increases as the central pressure falls to very low values; but, qualitatively the very deep typhoons have few features which could be used to distinguish them from typhoons of moderate intensity. The empirical studies relating maximum surface wind speed and central pressure [1, 2] indicate that the values of 950 mb. and 920 mb. would correspond to maximum wind speeds of the order of 125 and 150 knots.

4. INTENSITY STATISTICS

The total sample of typhoons for the years 1950-1957 consists of 136 cases and of these, 52 had central pressures equal to or lower than 950 mb. and 21 had values equal to or less than 920 mb. (table 1). This corresponds to an average annual frequency of 17.0 typhoons, and of these, 6.5 fell in the deep category and 2.6 in the very deep category.

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[2] The corresponding transition point in tropical cyclones in the Atlantic area tends to occur at a somewhat higher pressure.

Table 1. - Typhoon frequency statistics for western North Pacific and South China Sea areas for the period 1950-1957. Column I shows the total number of typhoons, column II the number of typhoons with minimum pressures equal to or less than 950 mb. and column III the number of typhoons with minimum central pressures equal to or less than 920 mb.

Year	I	II	III
1957	18	9	5
1956	14	5	1
1955	18	4	1
1954	15	10	4
1953	16	7	4
1952	21	5	3
1951	14	7	3
1950	20	5	0
Total	136	52	21
Average	17.0	6.5	2.6

It is interesting that the interannual variability in the number of typhoons is quite different for the three defined categories (table 1). If all cases are considered, the maximum and minimum years show deviations of the order of 20 percent above and below the mean value. The deviation about the mean is considerably larger for deep typhoons with a total range from 4 to 10 storms. The relative variability in the very deep typhoons is much greater with three years showing either zero or 1 storm and three other years with 4 or 5 storms.

The mean value of 17.0 for all cases agrees fairly well with the records covering longer periods. For example, statistics for the 30-year period from 1924 to 1953, listed by Ramage [6], give 17.5 and 1.9 as the mean annual number of storms of typhoon intensity in the western Pacific and South China Sea areas.

Statistics for the weaker storms in the 1950-1957 period have been prepared by using the trajectory charts of the Japanese Meteorological Agency. These tracks show all tropical cyclones in which the maximum wind speed was reported to be greater than 33 knots. Data taken from these charts show that the mean annual number of tropical cyclones for the 8-year period was 25.8, or about 9 more per year than listed in table 1 and 3 more than the mean annual frequency of tropical cyclones of all categories in the western Pacific and China Sea areas for a 70-year period shown in a summary by Ramage [6]. At least part of this difference is due to variations in the classification

Table 2. - Frequency of tropical cyclones in the western North Pacific and South China Sea areas during the period 1950-1957 with minimum sea level pressures in the intervals listed.

Pressure (mb.)	Number	Annual Average	Percent of total
>1000	12	1.5	6
990-999	58	7.3	28
980-989	33	4.1	16
970-979	21	2.6	10
960-969	22	2.8	11
950-959	11	1.4	5
940-949	11	1.4	5
930-939	12	1.5	6
920-929	7	0.9	3
910-919	8	1.0	4
900-909	9	1.1	4
< 900	2	0.2	1
Total	206	25.8	

criteria over the years, but there is little doubt that the aircraft reconnaissance programs in recent years have detected a larger percentage of the weaker circulations than were detected in earlier periods. Also, any one set of tracks may tend to record a larger percentage of the weaker cases in some areas than in others. For example, there is little doubt that more of the weaker cases in the South China Sea will be recorded on the track charts prepared by the Royal Observatory at Hong Kong than by those prepared by the Japanese Meteorological Agency in Tokyo.

Tropical cylones in the western North Pacific are routinely assigned feminine names and statistics can be presented on this basis. However, the named tropical cyclones in the North Pacific are those which, in the judgment of the forecaster, have attained or will attain typhoon force. The average number of named tropical cyclones over the period 1950-1957 was 18.8 or about two more than the mean annual frequency given in table 1. Obviously, typhoon-force winds were not observed in all named tropical cyclones. It is of interest to note that in the Atlantic, tropical cyclones are normally named when the maximum winds reach about 45 knots. Therefore, a simple comparison of the frequency of named storms in the two areas would be quite misleading.

The minimum central pressure value recorded for each storm on the Japanese trajectory charts for the years 1950-1957 has been used for the

Table 3. - Monthly statistics for the 1950-1957 period are shown in columns I - III for the three categories of typhoons listed in table 1. The mean number of typhoons per month and the monthly percentage frequency are shown. Similar statistics for tropical cyclones of all categories for a 46-year period, from [2], are shown in column IV.

Month	I		II		III		IV	
	Mean	Percent	Mean	Percent	Mean	Percent	Mean	Percent
Jan	0.1	1	0	0	0	0	0.8	4
Feb	0	0	0	0	0	0	0.3	2
Mar	0.2	1	0	0	0	0	0.4	2
Apr	0.6	4	0.1	2	0	0	0.5	2
May	0.6	4	0.6	10	0.1	5	1.1	5
June	1.1	7	0.2	4	0.2	10	1.4	6
July	1.8	10	0.4	6	0.4	14	3.3	15
Aug	3.3	19	0.9	13	0.5	19	3.6	16
Sept	3.8	22	1.5	23	0.2	10	4.1	19
Oct	2.8	16	1.4	21	0.5	19	3.3	15
Nov	1.7	10	1.0	15	0.6	24	2.0	9
Dec	1.0	6	0.4	6	0	0	1.2	6
Annual	17.0		6.5		2.6		22.0	

preparation of a frequency distribution of minimum central pressures by 10-mb. class intervals (table 2). Roughly one-third of all cases, which includes storms with maximum observed wind speeds as low as 33 knots, failed to deepen below 990 mb. An additional 30 percent did not reach minimum pressures lower than 960 mb. The number of cases below 900 mb. may actually have been slightly larger than shown in table 2. Dropsonde observations made in at least four typhoons in the 1950-1957 period reported sea level pressures below 900 mb. Presumably, some of these observations were either unavailable or were considered erroneous since they were not included in the individual typhoon reports or on the trajectory charts. The lowest dropsonde sea level pressures during this period were 886 and 883 mb. obtained in typhoon Nina of 1953. An even lower value of 877 mb. - which is believed to be the lowest sea level pressure ever observed - was obtained in typhoon Ida of 1958.

Statistics for the three primary typhoon categories are shown for individual months in table 3. In addition, the mean monthly statistics for a 46-year period [2] are presented for tropical cyclones of all intensities. The total sample of typhoons in the 1950-1957 period shows that the seasonal distribution was roughly the same as that of the longer period except that fewer cases were observed during the first few months of the year than given by the long term mean. This difference may be accounted for by the fact that the weaker cases, which are omitted in the 1950-1957 statistics, are relatively more prevalent during these months. Essentially the same pattern is shown for deep typhoons (category II) as for the complete sample but the pattern for very deep typhoons is somwhat different. There are only 21 cases in this latter classification but this sample suggests that the storms of this type are irregularly distributed from May through November.

5. GEOGRAPHICAL VARIABILITY

The tracks and central pressure information, which were available for typhoons during the period 1950-1957, have been used for examining some features of the geographical distribution of those storms in which the central pressure fell to values below 990 mb. The information has been combined into averages and frequencies for 5° latitude-longitude "squares." In some cases slow moving storms may have spent as long as three days in a 5° square and in other cases the storm may have spent only a few hours in crossing the corner of a square; however, each case is considered as a single occurrence of a storm within the specified square. The statistics presented for 5° squares have not been adjusted to compensate for the latitudinal change in area. This effect is negligible between adjacent latitude belts but should be considered when comparing frequencies for areas covering a large latitudinal extent.

The minimum central pressure of each typhoon during its traverse of a 5° square has been used in the preparation of mean minimum pressure values for the squares. For the most part, these values were read directly from the trajectory charts but in some cases where the track crossed only a small section of a square it was necessary to interpolate. The distribution of the mean minimum pressure values is presented in figure 1 and the total number of typhoons crossing each square during the 8-year period is shown in figure 2. Figure 1 shows that, in the mean, typhoons tend to be deepest in the latitude belt 10° -25°N. and in the longitude zone 125° -135°E. It follows that typhoons tend to fill in moving out of this area either westward toward the coast of Asia or northward toward Japan. The area of relatively low mean pressure between 25° and 30° N. latitude at the eastern border of the chart, although based on relatively few cases, appears to be a significant feature. The deep storms moving through this area - such as Olive which devastated Wake Island in 1952 - usually develop from disturbances which can be traced far to the east.

Comparison of figures 1 and 2 reveals that in general typhoons are deepest in areas where they occur most frequently, but there are differences in the patterns. The center of lowest pressure is farther south than the center of maximum frequency, and frequencies are quite high in the South China Sea west of the northern Philippines where the mean pressure is relatively high. Of course, the latter feature can be attributed to the filling which takes place as these storms move across the Philippines.

Many of the typhoons which attained low central pressures to the east and northeast of the Philippines began their deepening quite some distance to the east. This tendency is shown by figure 3 which gives the formation points of the individual typhoons, as defined by the 990-mb. pressure criteria. Five of the 136 cases fell either east or west of the area shown on figure 3. Difficulty

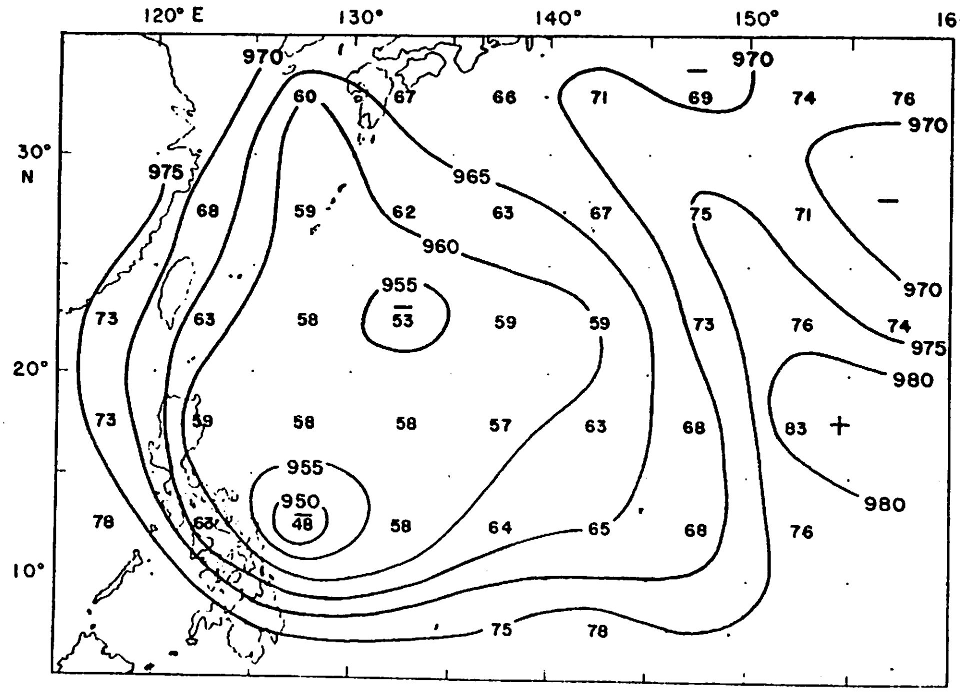

Figure 1. - Mean minimum pressure of typhoons during the period 1950-1957. The plotted figure at the center of the 5° latitude-longitude squares represents the computed mean pressure for the individual square in whole millibars with the first digit omitted. The number of cases used in computing the individual means is shown in figure 2. Mean values are not shown for squares in which there were fewer than five cases.

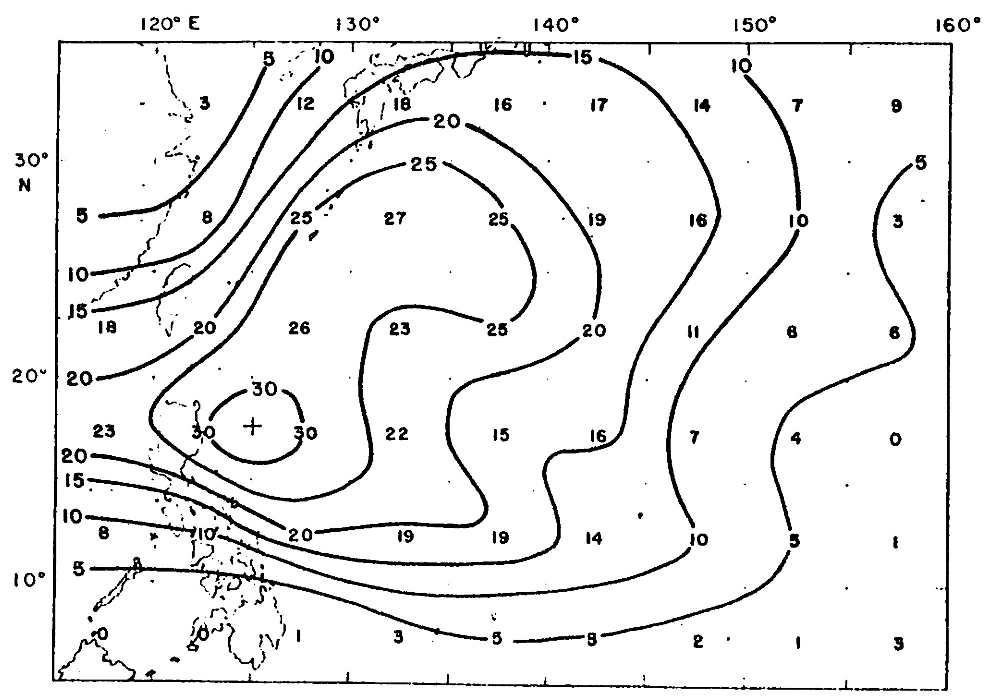

Figure 2. - Total number of typhoons traversing individual 5° latitude-longitude squares during the period 1950-1957.

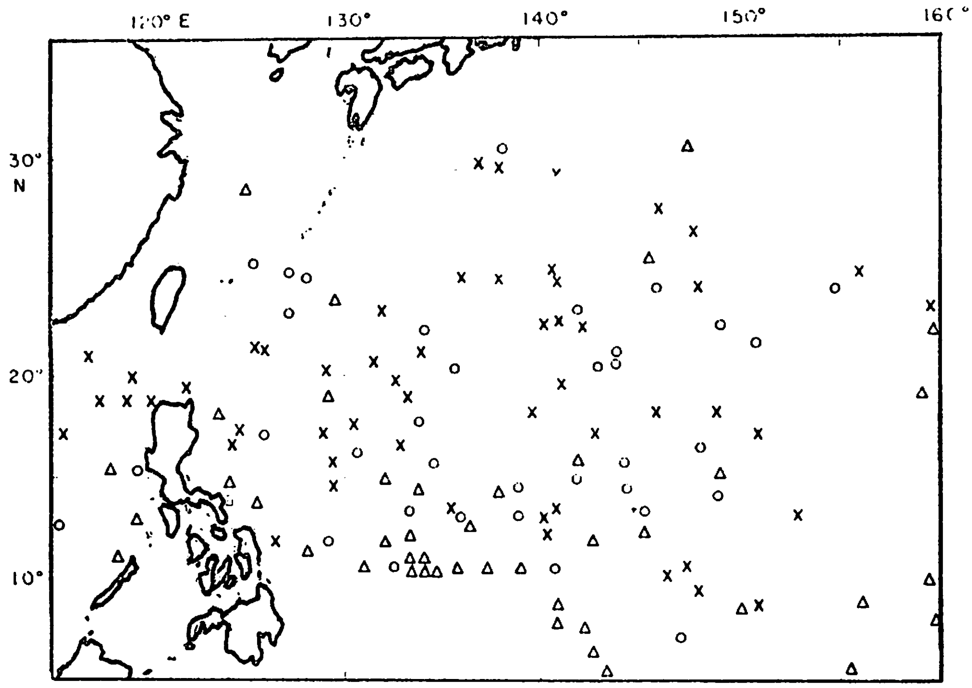

Figure 3. - Formation points of typhoons during the period 1950-1957. Typhoons forming in August and September are shown as crosses, those in July and October as circles, and those in all other months as triangles.

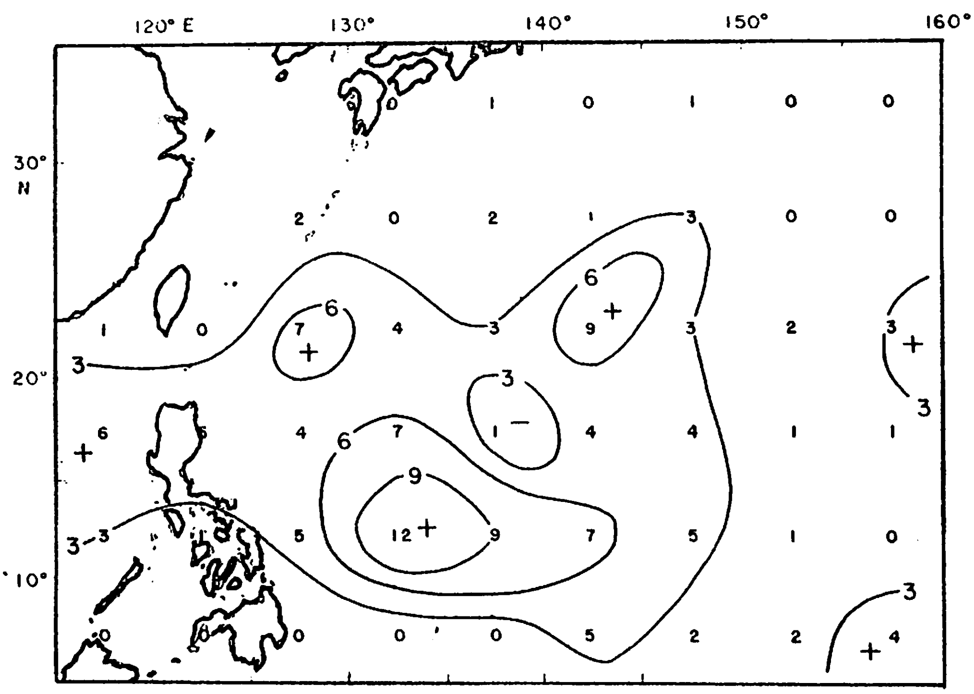

Figure 4. - Total number of cases of typhoon formation per 5° latitude-longitude squares during the period 1950-1957.

was often encountered in determining the accurate location at which the pressure fell to 990 mb. and in some cases the central pressure was well below 990 mb. when the first reconnaissance flight was made. The typhoon formation points are, therefore, subject to considerable error, but this information is used in such a way that errors of one day in timing have little effect on the results presented.

The data presented in figure 3 have been divided into three groups depending on the time of occurrence. The August and September storms are indicated by crosses, the October and July storms by circles, and storms for all other months by triangles. The formation points are spread over a very large geographical area and little organization is shown if all points are considered.[3] However, if the formation points for the different periods are considered, some interesting features are revealed. Typhoons from the months November through June tend to form primarily south of 15° N. and in the longitude belt between 130° and 145° E. The typhoons during these months are also relatively frequent in the area east of 155° E. The August and September typhoons tend to form over a very large geographical area but formations during these months are relatively rare south of 15° N. The total number of typhoon formations per 5° latitude-longitude square during the 8-year period is shown in figure 4. These data suggest that large variations in the frequency of typhoon formation occur over relatively small distances even over the open ocean. In particular, the area of infrequent formation between 15° and 20° N. and 135° and 140° E. stands out. It hardly seems likely that such marked geographical variability would be shown in the records for a much longer period. As would have been expected, the primary maximum of typhoon formation is found to the east of the location of the centers of maximum frequency of occurrence (fig. 2) and of lowest mean pressure (fig. 1).

The typhoon formation points tend to be concentrated in particular areas during some years. For example, most of the cases west of the Philippines occurred during 1952 and 1953 and most of those in the 25°-30° N. belt were observed in 1950. Geographical differences of this type, which have not been examined in any detail in this report, may prove to be important considerations in developing a better understanding of the typhoon formation process.

The geographical distribution of typhoons with central pressures equal to or less than 950 mb. is given in figure 5. As in figure 2, the values refer to the total number of cases observed in each 5° square during the 8-year period 1950-1957. The distributions in figures 2 and 5 are quite similar but there are a number of interesting differences. The frequency of typhoons in the vicinity of Japan is about half as great as in the maximum area east of the Philippines, but the relative frequency of deep typhoons in the Japanese area is much less. Also, the relatively high frequency in the China Sea west of the northern Philippines shown on figure 2 does not appear on figure 5. The distribution of very deep typhoons (fig. 6) is quite similar to that shown in figure 5. However, the frequency of these typhoons is low just to the east of northern Luzon where deep typhoons are relatively frequent. Also, the very deep typhoons were not found west of the Philippines or Formosa or north of 30° N.

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[3] Dunn in his study of areas of hurricane development [5] found a similar scatter for the Atlantic area.

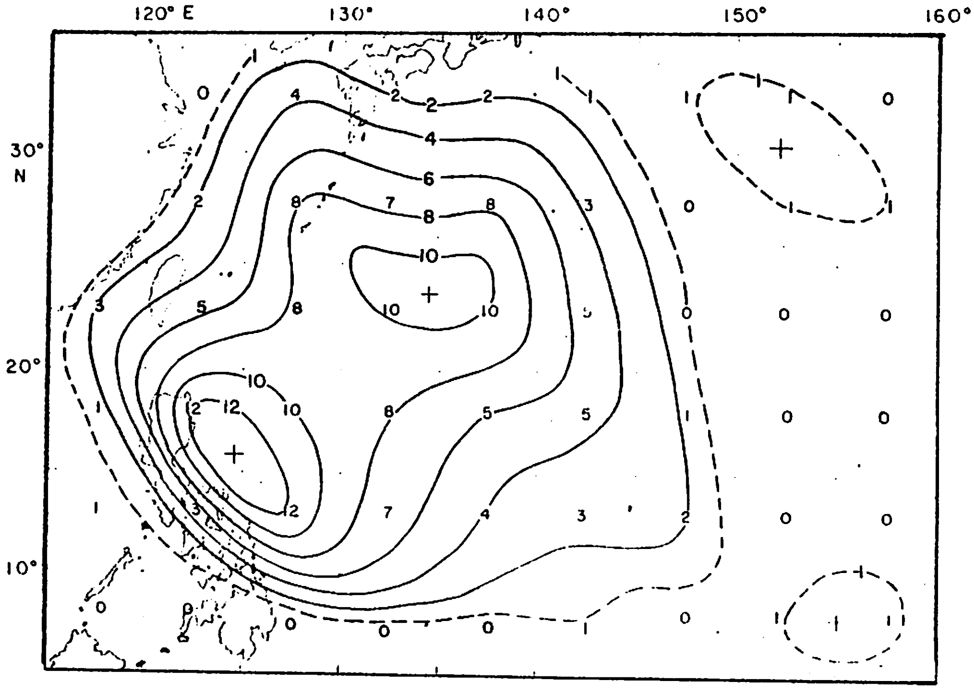

Figure 5. - Total number of typhoons with central pressures of 950 mb. or lower traversing individual 5° latitude-longitude squares during the period 1950-1957.

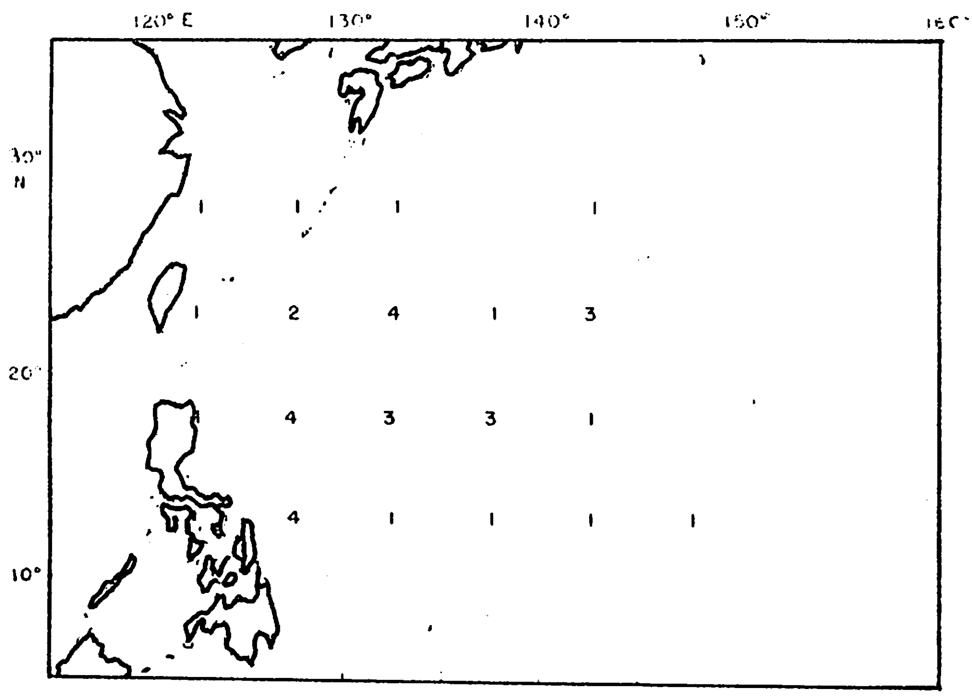

Figure 6. - Same as figure 5, except for typhoons with central pressures of 920 mb. or lower.

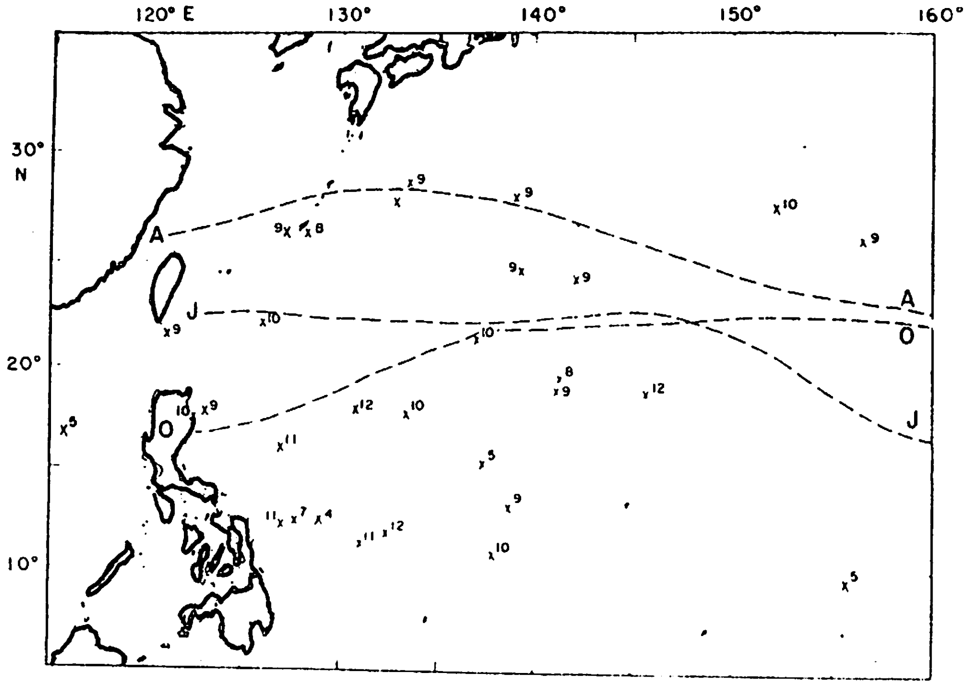

Figure 7. - Points of minimum pressure for typhoons with central pressures in range 950-921 mb. in the period 1950-1957. Numbers plotted at each point refer to the month of occurrence. Dashed lines show the position of the mean 82°F. sea surface isotherm for June (J), August (A), and October (O).

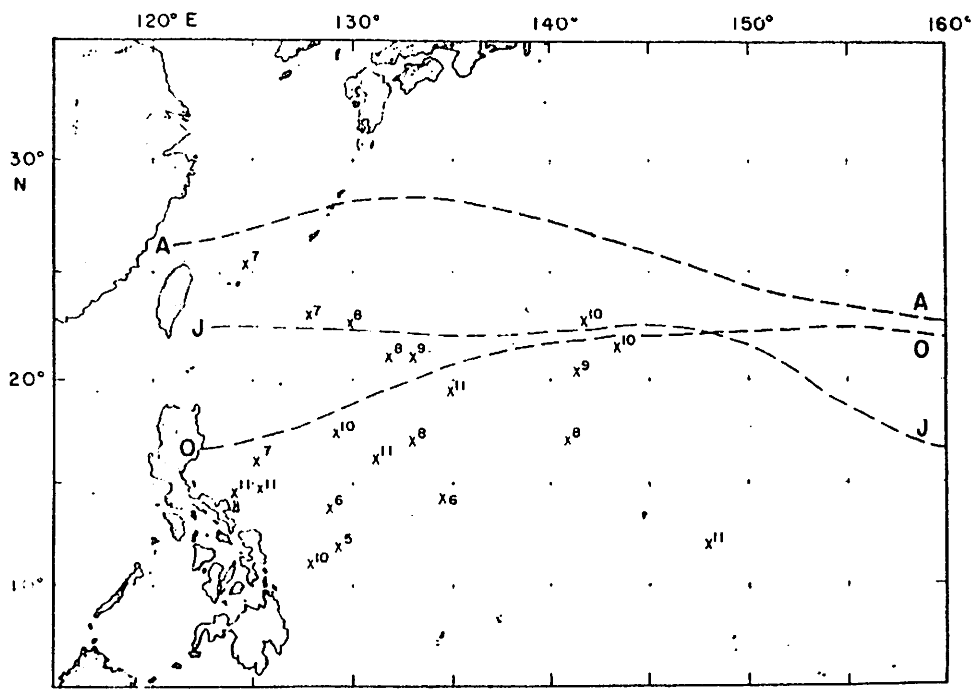

Figure 8. - Same as figure 7, except for typhoons with central pressures of 920 mb. or lower.

The geographical locations of the points of minimum pressure for typhoons with central pressures in the range 921-950 mb. are shown in figure 7 and those for the very deep typhoons in figure 8. Only one case during the 8-year period, typhoon Wanda of 1951, fell outside the area covered by these charts. The points are spread over large geographical areas but some seasonal variation is apparent. For example, most of the deep typhoons which reached their lowest pressures north of 22° N. occurred during July, August, and September. This feature suggests a possible association with the sea surface temperature, an effect which has been considered by several investigators (cf. [7, 8]). It was found that the 82°F. sea surface isotherm, as taken from an analysis of the data in the Atlas of Climatological Charts of the Oceans [9], showed a rather marked seasonal oscillation in the western Pacific which could be associated in a rough way with the seasonal variations indicated in figures 7 and 8. It is seen that nearly all the typhoons, in the two classes considered in these figures, which occurred during the months October through June reached their lowest pressure south of the June and October positions of the 82°F. isotherms. Also, the cases from July, August, and September which occur relatively far to the north are located in areas with warm mean sea surface temperatures.

Any meaningful association of the intensity of typhoons with warm sea surface temperatures must, of course, be made on a synoptic basis rather than with long-term mean values. The work of Miller [8] suggests the possibility of such an association and he has attempted to graph the minimum probable central pressure as a function of water temperature. Miller's temperature values corresponding to the 950 and 920 mb. dividing points used in this study would be roughly 83° and 86° F. Certainly water temperatures as warm as these are found in the western Pacific but it remains to be seen whether the very deep typhoons can be associated with areas of very warm water. However, since gradients in the mean sea surface temperatures are relatively weak during the months of most frequent typhoon occurrence, it hardly seems likely that the geographical concentration of the very deep typhoons (fig. 6) could be accounted for completely by variations in ocean temperature. The importance of the upper tropospheric circulation over eastern Asia and the western Pacific, as discussed by Ramage [6], is another factor which must be considered in any serious attempt to account for the geographical distribution of the very deep typhoons.

6. SUMMARY

During the 8-year period covered by this study, 136 typhoons were observed in the western Pacific and South China Sea areas. Roughly 40 percent of these storms had central pressures as low as 950 mb. at some time during their life history and about 15 percent fell as low as 920 mb. The interannual variability in the total number of typhoons was relatively small but the frequency of the deeper storms tended to be much greater in some years than in others. The seasonal distribution of the very deep storms, as indicated by this short period of record, failed to show the well-defined September maximum indicated in the overall typhoon frequency statistics. Typhoons with central pressures as low as 920 mb. were observed in every month from May through November with 43 percent of the cases occurring in October and November.

The primary typhoon formation areas tend to show a rather definite latitudinal oscillation during the year, with formations being relatively rare south of 15° N. during the months of highest overall occurrence. During these months typhoons often reach their lowest pressures north of 25° N. During the months November through May, typhoons form primarily south of 15° N. and the lowest pressures are usually attained south of 20° N. The number of typhoons forming per unit area varied appreciably over the ocean area between the Philippines and the Marianas. This high variability may have arisen from chance since the period of record was relatively short; it would hardly seem likely that similar statistics covering a much longer period would show such large differences between adjacent 5° latitude-longitude squares.

The very deep typhoons were concentrated in a fairly limited geographical area east and northeast of the Philippines. In general these storms showed considerable filling long before striking the coast of China or Japan or reaching 30° N. There were no storms of this intensity in the South China Sea and only one case occurred east of 145° E. during the 8-year period.

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