WOODS HOLE OCEANOGRAPHIC INSTITUTION

Reference No. 60 - 33

Tropical Island Rainfall

A Study of the Rainfall Distribution of Trinidad,

West Indies

WOODS HOLE, MASSACHUSETTS

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A Study of the Rainfall Distribution of Trinidad, West Indies

by

Michael Garstang

Woods Hole Oceanographic Institution[1]

Woods Hole, Massachusetts

October, 1959

Reference No. 60-33

[1] WHOI Contribution No. 1085

Abstract

The study is based upon the concept that climatology cannot be divorced from the dynamics of weather. An attempt is made to outline the meteorological framework of this region of the tropics. The rainfall of Trinidad is then discussed within this framework. The mean annual distribution of rainfall over the island forms a basis for the discussion of monthly distributions. Seasonal variation is pointed out and related to broad scale migrations of the subtropical anticyclones and the equatorial trough. The dual rainfall maximum occurring during the wet season is, in turn, related to the synoptic scale patterns of this season. Distribution is then examined with reference to the moist layer, wind direction and speed. Diurnal distribution is treated in detail and the mechanisms giving rise to the well-defined distribution patterns are discussed. Finally some attention is paid to shower amounts and distribution. In conclusion the rainfall of the island is summarized by relating the seasonal variations to the broadscale meteorological background and the actual distribution to the local scale influences.

1. Introduction

During the past two decades it has become increasingly evident that a purely climatological and statistical approach to the study of rainfall distribution is inadequate. Whereas data must be compressed in some manner, tropical and equatorial climatology has long suffered from the ills of averages and means. The climate of a region is based upon the day to day weather, which in turn depends on dynamical factors. In many ways, then, the interpretation of climate depends upon the degree to which we understand the mechanisms which cause the changes in weather.

Thus in a study such as this, it is felt that the choice of the methods of reduction and representation should be governed by what is known of the synoptic- and local-scale effects, which in turn, should be interpreted in terms of what is known of the dynamics of the region.

The interpretation of the broadscale meteorological features of low latitudes depends not only upon the particular approach adopted by the individual but specifically upon the longitudinal region to which the study applies. The liberty is, therefore, taken to summarize as briefly as possible that which the writer considers to be the broad-scale meteorological background governing the precipitation of the West Indian island of Trinidad.

Data accumulated during the past 10 - 20 years in the tropics have provided a fairly accurate description of the lower layers of the atmosphere of these regions (1, 12, 13, 16). The seasonal march of the tradewind belt is fairly consistent, so that for the region about 10°N lat, 60°W long, the wet and dry seasons are confined to the months of July to November and January to mid-April respectively, with transitional periods in between.

Observations collected in Trinidad by the writer (3), show that the wet season is characterized by a deep, horizontally homogeneous, easterly current. The height of the trade wind inversion fluctuates with the passage of vortical or wave-like disturbances, but in general, the height of the 5 gm per kg mixing ratio line (see Fig. 3) used here as an arbitrary measure of the depth of the moist layer, is about 12000 feet during the wet season.

Although the major synoptic disturbances are of the low level vortical or wave type, a considerable number of high level disturbances of either tropical or extratropical origin affect the region. Complex situations involving more than one of the above disturbances also occur. Hurricanes rarely affect the island of Trinidad directly, but the indirect results, both in the form of unusually fair as well as bad weather, may be felt.

At the onset of the wet season, usually by the beginning of the month of June, successive wave-like perturbations in the wind field affect the island. During this early period the structure of these disturbances appears to resemble most closely the easterly wave as described by Riehl (13, 14). Frequently, however, the distribution of weather is considerably more complex and the observed structure is more similar to that of the equatorial vortex discussed by Palmer (11, 12) in the Pacific or the equatorial cyclone observed by Riehl and Byers (15) in Venezuela. Up until about the middle of the month of July the center of the wave or vortical type disturbance probably never moves to the north of Trinidad. But it should be particularly noted that under these conditions the zone of maximum convergence which most frequently lies in a crescent shape to the north and east of the vortex, moves on a track which will affect Trinidad.

The progressive northerly shift of the perturbation tracks is undoubtedly associated with both the northward displacement of the mean position of the equatorial trough and the subtropical anticyclones. While the mean monthly position of the equatorial trough is never (18) found to be north of Trinidad, it may, as Riehl notes (13, p.13) fluctuate on a synoptic scale as much as five degrees to the north of Trinidad. These most northerly excursions reach their maximum during September and October. Thus after mid-July the number of occasions that the centers of the perturbations move to the north of Trinidad steadily increase and reach their maximum coincident with the most northerly penetration of the equatorial trough both in its mean and synoptic positions. It therefore follows that during this period the zones of maximum convergence associated with the perturbations most frequently travel across to the north of Trinidad.

With the southward migration of the trough and pressure systems the cycle is repeated in reverse, so that from about mid-November onwards the centers of the perturbations are once more all south of Trinidad.

The broad features of the above progression of disturbances during the wet season can be observed in Table I which shows the mean monthly percentage frequency of the 2000-foot wind direction with average velocities, in knots, for each 30 degree interval. Mean monthly velocities regardless of direction are also shown. These results were obtained from three years (1953, 1954, 1955) of daily pilot and rawindsonde ascents taken at 1400 and 2300 LST[2]. Thus the distribution is considered to be representative of the low level flow over the island and any variation in detail that would result if a longer record were used would not, it is felt, change this basic monthly distribution.

The main features that should be noted from Table I are:
(1) The establishment soon after November of the northeast trades. These reach their maximum during February, March and April when characteristically they exhibit a high degree of constancy with which is correlated the maximum wind speeds. So that by March

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[2]Local solar time at 60 degrees West Longitude.

98.4% of the winds occur between 40 and 90 degrees with a mean speed of 18.1 knots.

(2) This pattern is replaced by a more southeasterly flow which gradually decreases in strength. By August and September a considerable degree of variability has entered into the picture. The mean monthly speed has now dropped to 8.8 knots and wind direction fluctuates from 340 degrees through north to 270 degrees. The interrelation between the wind field and the broadscale conditions is marked. Conditions in fact become typical of those associated with incursions of the equatorial trough and the consequent movements of perturbations to the north of the island.

(3) There is a fairly rapid return to first easterly and then north-easterly flow during November and December.

The dry season as just shown, exhibits the strong influence of the north east trades and, although there is no surface discontinuity in the temperature and moisture fields, temperate zone disturbances in a much modified form occasionally penetrate the region in the upper levels. The deep moist layer is absent and on the average the height of the 5 gm per kg mixing ratio line is about 9000 feet.

With this outline then, it can be seen that all discontinuities in the horizontal plane which may arise, for example, from such factors as differences in air masses, may be discounted. In fact, whatever factors now enter the picture, it becomes obvious that they involve vertical transportation of air, either in the form of convection, orographic lifting or widespread convergence, or with all three factors in a single complex pattern. Thus, when dealing with the rainfall of Trinidad, the factor that transcends all others in importance is the vertical transportation of the lower and more moist layers of air. In consequence, not only do the organized meteorological disturbances play a major role in precipitation, but are in themselves classified and fall into defined seasons. Furthermore, for the same reason, the importance, particularly from day to day, of local convection, convergence, relief, wind speed and direction, etc. become far greater than in temperate regions. Finally, with uplift taking place within the thermodynamically unstable atmosphere outlined above, the form of precipitation is predominantly that of the shower type as opposed to steady rain.

With this outline it will be seen that the methods of analysis used bear these factors in mind and the study as a whole is related specifically to this background.

2. Situation and Relief

The island of Trinidad lies between 10 degrees 3 minutes and 10 degrees 44 minutes north latitude and between 60 degrees 55 minutes and 61 degrees 56 minutes west longitude. Politically it is considered the most southerly of the West Indian islands, but geographically and geologically it should more properly be regarded as outlier of the South American continent, from which it is separated by a strait only 7 miles in width. It should, however, be pointed out here that not only is the main portion of the island well removed (more than 80 miles) from the mainland but also that it lies to the east of the mainland. Thus it is felt that despite this proximity Trinidad is probably representative of island rainfall.

The island falls into a number of fairly obvious topographical regions which can be seen from Fig. 1.

(i) A chain of mountains, the Northern Range, runs right across the north of the island, being a prolongation, as a series of parallel ridges, of the coastal cordillera of Venezuela. El Tucuche and Aripo, two peaks in the Northern Range, just exceed 3000 feet.

(ii) A chain of hills, known as the Central Range, runs diagonally across the center of the island from north-northeast to south-southwest, the greatest elevation being Mt. Tamana (1009 feet). Another chain, though much less distinct, borders the south coast, merging for much of its length into the general peneplain, but in parts standing up to heights over 500 feet.

(iii) The lowlands consist collectively of dissected alluvial terraces, dissected peneplain, both of which range in elevation between 50-100 feet, and several large areas of almost perpetually inundated swampland.

3. Rainfall

Fig. 1 shows the location of the eighty-eight rainfall stations used in the analysis. These stations were selected from the 170 rainfall stations existing in Trinidad. Selection was based upon length of record, continuity, and the actual siting of the gauge itself. All except one station, Cocal, (4 years), have records greater than 5 years in length. Fifty-four of the stations have records of 20 years, 12 between 15-19 years, 11 between 10-14 years and 10 between 5-10 years. Although the fact should be borne in mind that stations with records of unequal length are used, it is felt that this does not affect the basic distribution pattern.

The mean annual rainfall distribution over the island is shown on Fig. 2. The range is from more than 300 cm in the northeast where individual stations, mainly in the vicinity of Hollis Reservoir, record an annual rainfall of over 330 cm, to below 127 cm in the northwest and southwest of the island.

Bearing in mind from Table 1 the prevailing easterly trade flow and the relief of the island, the relationship between the two is most marked. Nevertheless, it appears to be the orientation of the island with respect to the prevailing wind that plays the predominant role. Instead of the highest rainfall belt lying along the Northern Range it is, in fact, at right angles to it. The Central Hills appear to play some role in this distribution and may be responsible for the zone of maximum rainfall lying further inland from the east coast than might otherwise have been the case.

Examination of the rainfall distribution during the wet and the dry seasons show much the same pattern as the above. During the dry season the increase in wind speed and the greater northerly component of the wind create an elongation of the maxima along the Northern Range. Similarly Stidd and Leopold (17) found the monthly rainfall distribution patterns of Hawaii to fluctuate little between the wet and the dry seasons, a fact which formed in part, the basis for their quantitative analysis.

With a similar approach to that of Stidd and Leopold, using the two variables, mean annual rainfall and mean monthly rainfall, it was felt that a more accurate description of the seasonal rainfall might be obtained. Hence monthly mean rainfall was expressed as a percentage of the mean annual rainfall for each station. This was then plotted on a set of twelve monthly charts on which lines of equal per cent were drawn at one per cent intervals. Without reproducing these figures the broad features can be readily described.

The most important features that emerge from this analysis are (1) three distinct periods are found which coincide with the seasonal variation of the wind and moisture field in the lower troposphere. Fig. 3 shows the mean height of the 5 gm per kg mixing ratio line and the deviation from the mean where:

$$\text{Standard deviation } \sigma = \sqrt{\frac{(r - r_k)^2 m_k}{\Sigma m_k}}$$

This distribution was obtained from the analysis of a period of 5 years of radio-sonde ascents over Trinidad on a weekly basis. It will be seen that there is a distinct period from June through October with a consistently high moisture level. Similarly, there is a shorter period of January, February and March with low values. Between these two periods the level either climbs or descends, but it is significant to note that, whereas the departures from the mean during the mid- "wet" or "dry" period are relatively small, they are greatest during the transitional period. (2) During the dry season the percentage precipitation received at any one place is low, nowhere exceeding 8 per cent of the annual precipitation, during any one month. During this period the distribution follows the relief of the island fairly closely, that is, areas of high relief receive high rainfall, which suggests that, during a period when disturbances of a synoptic scale are few, local features govern the distribution of the precipitation. (3) During the wet season the monthly percentage of total precipitation is high. A double maxima is, however, exhibited - the first peak occurring for most places during July and August while the second occurs during November. During these months the lowest percentage rainfall received by any one place is 9 per cent while the highest is 16 per cent.

From the introductory comments on both the synoptic disturbances affecting the island and the wind field, the explanation for this double maximum is most likely to be found in terms of the frequency of synoptic disturbances affecting the island as well as the coincidence between the precipitation zones of the disturbances and the island. So that during July the zones of maximum convergence and hence maximum precipitation most frequently move directly over Trinidad. While the number of disturbances probably vary little from season to season there may be considerable variation in the relative position of the disturbances and the island. Thus while the onset of the wet season is fairly abrupt, the actual amounts occurring during the months of June, July and August are subject almost entirely to the maximum frequency of coincidence between the disturbances and the island. Therefore in individual years it is possible for any one of these three months to emerge with the highest total monthly rainfall. During the months of September and October the number of disturbances which move across to the north of the island reach a maximum. The lower troposphere, however, continues to be extremely moist to considerable heights and in fact it is during this period that the trade wind inversion virtually disappears. Furthermore the light wind conditions which prevail favor both convective development over the island during the daytime as well as the development of local sea and land breeze convergence lines. Therefore, there is little reason to expect a decrease in rainfall amount at this time. However this relative minimum not only occurs in the mean but is, in fact, a very real feature and bears the name in local French patois of "petit careme", literally "little lent", which refers to the major dry season which occurs during Lent, and thus the expression has the idiomatic meaning of "little dry season". The fact that a minimum occurs at all can thus only be ascribed to the minimum coincidence of the perturbations which are now moving into the Caribbean predominantly to the north of the island. On the basis of this argument the November maximum follows as a matter of course. It assumes the role of a secondary maximum mainly because the incursion of the northeasterly trades and the consequent lowering of the moisture level follows fairly rapidly in the wake of the southward migrating equatorial trough.

It is further noted that during the wet season relief no longer dominates the pattern as it did in the dry season. Finally during the transitional periods between the wet and dry seasons both distribution and amount of rainfall become haphazard.

These observations agree in general with those of Yeh and others in Hawaii (19) and Jordan in Guam (6).

So that, whereas one might draw a graph to represent the annual distribution of rainfall for the island of Trinidad, it is felt from this analysis that it will not reflect the true conditions, but will, in fact, mask them. The annual distribution of rainfall should rather be described in the above terms and the examination of any one place will immediately point out variations due to location and orientation.

On the basis of the foregoing, attention is now directed specifically to the two seasons and to the two factors, prevailing wind and relief which seem to control the spatial distribution of rainfall across the island. Furthermore, in light of the mechanisms involved in producing rainfall over Trinidad, the diurnal distribution is also brought under consideration.

In order that the necessary detail be obtained, eleven automatic rainfall stations were selected as shown on Fig. 1.

As before, attention was paid to the situation and aspect of each station. Data from each station had to be extracted manually from the actual recording charts. The immense volume of work involved in extracting this data from daily records limited the period examined to three years. So that, although conscious of the limitation imposed by such a short period, it is again felt that the results obtained are sufficiently representative and would suffer only minor modification if a longer period were analysed.

Firstly, an attempt was made to examine the relationship between wind speed and direction, relief and rainfall distribution.

In an effort to segregate disturbed from undisturbed conditions, the height of the 5 gm per kg mixing ratio line was taken as a measure of widespread divergence or convergence which must be associated with any synoptic scale disturbance. A value of 11,000 feet was adopted for the wet season of the three years 1953, 1954, 1955 and the data examined as follows:

The twenty-four-hour period was broken down into two basic periods of day and night. These were then subdivided into two periods each - from 0800 LST to 1200 LST and 1200 LST to 1800 LST; and from 1800 LST to 2400 LST and 2400 LST to 0800 LST. It will be noted that these periods are of unequal length - 4 and 6 hours during the day and 6 and 8 hours during the night. Keeping in mind the two factors of locally generated convection and of advection, it is considered that any showers occurring during the night up until 0800 will not be due to daytime convection over the island. After 0800 under unstable conditions, since a cumulus cloud may develop from inception to maturity in the space of 30-60 minutes (13, p.119) daytime convection may begin to play a part, although advection and orographic lifting remain the main mechanism during this period. With maximum heating after 1200, noon was felt to be the time to start the second daytime period, lasting until 1800 LST. All convective processes over land are considered to have ceased by 1800 LST; it is of interest to observe how frequently precipitation occurs during the early part of the night over the island, hence the final period was chosen as 1800 to 2400 LST. Furthermore, this breakdown was confined to the wet season for which June, July and August were selected as representative for the above three years. Each of these four diurnal periods were then examined.

Table 2 shows the northern east-west line of self-recording stations under conditions where the moisture level is above 11,000 feet. It can be seen that when the wind direction is greater than 90 degrees, and for all three wind speed groups, particularly when the wind speed is above 20 knots, almost all stations show at least one period during the 24 hours with a shower frequency near 70 per cent. Whereas Matura on the east coast exhibits an almost uniform distribution through the 24 hours, Hollis Reservoir shows frequencies of over 80 per cent between 1800 and midnight. Progressing eastward across the island there is a reversal in the periods during which the showers occur so that maximum frequency at the Golf Course station occurs during the afternoon.

With the same conditions of moisture level and wind speed, but with wind direction less than 90 degrees, there is a sharp drop in the frequency of showers over the eastern stations. The distribution over the western stations, however, remains much the same.

Shower frequency with the moisture level below 11,000 feet shows a marked decrease, as is seen in Table 3. For almost all speeds and all wind directions showers occurring in the western section of the island are confined to the afternoon periods. During the night periods when the wind direction is less than 90 degrees and the speed between 0-10 knots virtually no showers occur at the Golf Course, Forres Park and Penal. Western stations exhibit a marked decrease in frequency, with only a few day periods with showers occurring on more than 50 per cent of the occasions. In fact for any one station, no showers occur for at least one period on between 90-100 per cent of the occasions that these conditions of moisture level, wind direction and speed prevail.

From this description it is readily observed that both the height of the moisture level and wind speed play important roles in the frequency of showers. While it is almost certain that on most of the occasions when the 5 gm per kg mixing ratio level was above 11,000 feet some disturbance was in the vicinity of the island, this fact dominates only the frequency, but does not affect the spatial distribution which remains subject mainly to diurnal influences, relief and to a lesser extent wind speed and direction. Similar correlations were noted by Yeh and his collaborators (19) in Oahu, where there was a direct correlation between rainfall and the strength of the trade wind. Bearing in mind, however, that the distribution discussed in Trinidad refers only to the wet season the additional variable of the height of the moisture level is felt necessary. Somewhat in contrast are the findings of Jordan in Guam (6) which reveal that the more persistent showers during the wet season are associated both with weak flow and middle cloud. These conditions seem only to resemble the background conditions over Trinidad during the period September-October discussed earlier.

It is felt that the above conclusions justify examining time and space distribution of rainfall over the island without the separation of rainfall primarily associated with synoptic disturbances from that associated with local mechanisms, since it has been indicated in the preceeding that synoptic systems influence the amounts and not the spatial distribution. Except for the subdivision into wet and dry season, diurnal distribution of rainfall is therefore examined without any attempt to relate it to specific meteorological conditions.

Using the same eleven automatic gauge rainfall stations as before, the average precipitation for each of the four time periods at every station has been expressed as a percentage of the mean total seasonal precipitation at that station during the years 1953, 1954, 1955.

Figs. 4 and 5 show these distributions for the dry and the wet seasons. The most marked feature of this series of charts is the regularity of pattern and the complete diurnal reversal of the distribution. Relief appears to play only a small part during the two periods 1800 - 2400 LST and 0800 - 1200 LST. It should, however, be borne in mind that a percentage distribution is being shown here and these charts must therefore be related to preceeding material which then reveals the actual role played by relief.

More so than the wet season, the four dry season charts of Fig. 4 show the pronounced effect of advection, convection and locally developed convergence. During the night period when it is felt that the only mechanisms involved are advection of showers developed off or over the east coast and orographic lifting (disturbances have been shown to be equally subject to these mechanisms), the penetration of showers decreases progressively from east to west across the island. During this season the Northern Range, the east and the southeast coasts receive more than 25 per cent of their rainfall during the early part of the night, while the west coast, northwestern and southwestern areas receive below 10 per cent.

During the period 2400 LST to 0800 LST all effects of relief disappear and the isopleths become regularly spaced and orientated almost wholly north-south. The percentage precipitation falling during this period now exceeds 30 per cent over the entire eastern part of the island, increasing to 45 per cent over the northeastern areas. So that, even though the preceeding discussion indicated that certain areas of the island received a considerable part of their precipitation during the night period, it is, nevertheless, surprising that the northeastern sector receives as much as 75 per cent of its precipitation during the night period in the dry season, and that in fact, the eastern half of the island is virtually under a night rainfall regime. This factor alone may be extremely significant in evaporation-transpiration processes (21).

The daytime patterns show a complete reversal of the night distribution. As was the case during the first night period, the pattern during the period 0800-1200 LST is somewhat less organized. Relief again appears to influence distribution, but here it is found that high ground receives the lowest percentage of its precipitation, while the low-lying areas in the west show quite high percentage of rainfall. By the afternoon period of 1200 - 1800 LST complete reversal has taken place with much of the western sector of the island receiving over 30 per cent of its precipitation during this period; rapidly increasing westward to over 50 per cent, so that the western coastal area and peninsulas receive over 75 per cent of their rainfall during the day in the dry season. Again it should be noted that not only is the western half of the island the driest but that it receives the bulk of its showers during the afternoon. Conversely, much of the eastern portion of the island receives less than 35 per cent during the daytime period. The wet season patterns of Fig. 5 despite the far higher actual precipitation, repeat all the essential features of the dry season distribution, with ever greater emphasis upon the afternoon regime over western Trinidad. This contrasts strongly with the diurnal pattern found by Jordan on Guam (6) where during the wet season there is little diurnal variation.

A complete explanation of the dirunal distribution, which, in turn, largely governs the entire rainfall distribution of the island, would depend both upon a more detailed and a more comprehensive study of the dynamics of Trinidad weather. This equally would depend upon the observational data available. Recognizing the present limitations, it is felt justified that some of the mechanisms suggested by this rainfall distribution should be pointed out.

Precipitation and the diurnal variation of cloud cover over the open tropical and equatorial oceans is a problem which has by no means received adequate study. Some indications were obtained from data collected during a 16-day period in August 1957 on an ocean station some 480 nautical miles east of Trinidad, by the

Woods Hole Oceanographic Vessel R.V. CRAWFORD (4). During the period that the CRAWFORD was hove to on station, 84.32 mm of rainfall were recorded. Based upon observations at the time and subsequent analysis, all the rainfall recorded, excluding 0.51 mm, was associated with disturbances. Precipitation was furthermore confined to fairly short periods, the longest of which extended over a period of 42 hours. Although a longer period of observation would be required to confirm the CRAWFORD results, these do, however, indicate very strongly that background rainfall is of slight importance, while by far the greater part of precipitation occurring over the open ocean in these low-latitude regions is confined to disturbances.

This is borne out by findings of Riehl in Hawaii quoted by Leopold (10) where 80-90 per cent of the total rainfall was associated with what Riehl labelled "rainstorms".

Furthermore, this tends to confirm both what has been shown in this study as well as in others (6, 10, 17, 19) that the rainfall over an island such as Trinidad may be subdivided into two categories; that due to synoptic disturbances and that resulting primarily from the interaction of synoptic and local effects. Here it has been seen how seasonal trends are best explained in terms of the synoptic scale disturbances while distribution is best described in terms of local effects. Superimposition of disturbed conditions upon the local regime does not mask the latter and a measure of the contirbution of either is possible.

Examining the diurnal wind cycle as the land breeze cell gradually establishes itself over the island during the night, interaction between land breeze and the prevailing trade wind over the east coast areas begins to take place. No actual change in direction of the prevailing current need be postulated, as seems to be thought necessary by Kimble, but rather a marked weakening of the wind field in the lower layers (at least up to 2000 feet) probably occurs as a stable layer develops over the central parts of the island during the night. This may be thought of as a dome-like block which creates a region of speed convergence along its eastern sides. Fig. 6 shows the diurnal variation of the surface wind at Piarco taken from a ten-year period of anemometer records. The anemometer has an effective height of $57\frac{1}{2}$ feet and is ideally exposed. Piarco Airfield, as can be seen from Fig. 1, is fairly representative of conditions over central Trinidad. While Fig. 6 shows no more than the stabilization of the air at night at this level, it is regarded, within this environment of persistent trades, as some measure of the above hypothesis. Under favorable conditions the early morning development of cumulus off and over the east coast of Trinidad is marked. Due to these factors, showers may occur over the whole eastern coastal area some spreading inland, but decreasing rapidly westwards. Soon after dawn the whole system breaks down leaving in its train the more complex pattern found on the 0800-1200 LST chart.

Particularly under conditions of light wind speed there is the reverse interaction off the western coastal areas between the trade and the sea breeze. For the development of afternoon showers purely by this mechanism, more critical conditions are thought to be necessary. Under light trade wind conditions (which occur frequently during the mid-wet season) the sea breeze off the Gulf of Paria begins to oppose the trade flow over the island creating a convergence zone in the vicinity of the western coast line. Although, under light trade wind conditions optimum development may take place, there again need not necessarily be any actual change in wind direction, even though as pointed out by Riehl and others (13, p.104-105) the sea breeze on the leeward coast is invariably stronger than its nighttime counterpart. It is more likely however that unless the trade flow is light these conditions of convergence will occur off-shore and the resulting showers will not affect the island. This zone of cloudiness is probably augmented by cumulus clouds developing by convective processes over the central and western parts of the island and being advected into it as well as by cumulus over the sea going through the diurnal cycle already noted. Thus the whole feature reaches its maximum development during the early afternoon. At times this feature resembles a squall line and severe downdrafts and gusts affect the west coast. The accompanying showers, although they appear to spread farthest inland along the Northern Range, rarely affect more than the western half of the island. It is therefore seen that the afternoon period consists of a complex of interacting mechanisms of convective cells, local convergence and relief, upon any or all of which may simultaneously be superimposed the large-scale convergence field of synoptic disturbances.

The land sea-breeze circulation has been fairly extensively studied (2, 5, 8, 9) and associated with the locally generated convergence lines discussed above. Leopold (8) uses the Hawaiian group of islands as a basis for classification of type of land and sea breeze convergence zones. According to this classification Trinidad may be classified as the Maui-type during the day and the Mauna Kea-type during the night. General classification is therefore difficult and must be modified according to the complexities of local effects involved in individual cases. Finally it might be noted that differential fraction between land and sea may play an important part.

Thus, in many ways the diurnal distribution of showers over the island best succeeds in classifying the rainfall of the island. Here the various operative mechanisms appear to be segregated and each phase can be examined as an entity. It is quite possible that further subdivision along these lines would succeed in even greater clarification, but it is believed that more quantitative confirmation of these observations is required rather than greater detail. A useful step in this direction would be low-level wind studies over the island such as those used by Byers and Rodebush in studying the causes of the thunderstorms of the Florida peninsula (2).

Shower intensities over the island were also examined. These exhibited the expected trend showing highest intensities in the highest rainfall areas and over areas of greatest relief. Although it is clear from this and previous comments that any single station is not representative of the island as a whole, it is felt that the shower amounts and durations recorded at Piarco and shown by Fig. 7a to 7d, based on a 10-year period, give a fair guide. The essentially shower type precipitation as well as the common pronounced skewness of the distribution is readily recognized from these figures. In the dry season showers are mostly less than 0.4 mm and usually last six minutes or less and rarely last more than 18 minutes. In the wet season the amounts are most frequently below 1.0 mm and again last mainly for six minutes or less and occasionally more than 18 minutes. Cases of heavy falls or periods of protracted rain occur almost solely in the wet season and can undoubtedly be associated with the passage of marked disturbances over, or in the vicinity of the island.

4. Conclusion

The annual rainfall distribution over the island of Trinidad follows the seasonal migration of the major pressure and wind systems. Maximum precipitation occurs when the easterlies attain their greatest depth which, in turn, is when the frequency of synoptic scale disturbances is greatest. But instead of a single maximum two peaks occur. The primary peak is apparently related to one set of meteorological conditions governed mainly by the deep moist easterlies in which are imbedded the synoptic disturbances which are primarily responsible for the increase in rainfall in the wet season. With the approach of the equatorial trough zone the relative position of the island and the equatorial waves or vortices change and for a short while during September and October the optimum conditions fall off and a relative minimum appears. With the southward movement of the equatorial trough and the associated disturbances the relative position of the island and the most frequent synoptic disturbances change resulting in a secondary maximum in November.

These facts alone are of considerable importance but it is seen that it is not until they are integrated with the complex set of local effects that the rainfall distribution is clarified. Local effects appear to remain in control even when overlain by disturbances. Hence, it is seen that the distribution of rainfall over the island during both the wet and the dry season is essentially the same. The amount of precipitation is however a function of the synoptic disturbances and it therefore follows the seasonal pattern of these disturbances.* From this it is felt obvious that reliance upon techniques of averages and mean isoyet maps would succeed only in oversimplifying the problem. Based upon what is known of the dynamics of the tropical and equatorial regions the tools of climatology must

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*Clearly the synoptic and local scale effects interact but by the techniques adopted some attempt can be made at s eparation which in turn emphasizes the rold of local and synoptic influences on the precipitation of the island.

either be adapted or recreated if adequate description of the elements of climate are to be obtained. Whereas quantitative analysis is essential it is believed that qualitative description with the proper basis can contribute both original thought as well as augment the existing knowledge of tropical and equatorial weather.

As has been obvious from the work of many others in this field there are a number of aspects of such a study of direct use for local forecasting. Furthermore, the results of this study have certain implications which it is hoped can be followed up in later work. For instance if the conclusion that the spatial and diurnal distribution of rainfall is independent of the synoptic disturbances is correct then it is certainly possible that for specific conditions the background rainfall of the island can be determined. With a method for doing this established, the amount of rainfall due to individual disturbances can be determined. From this, in turn, a measure of the intensity of the storm can be made, possibilities of carrying out heat transport calculations are opened up which in turn have more general application. Similarly it is possible that rainfall reports could be used in a more quantitative sense as forecasting tools. In tropical and equatorial regions where one of the greatest handicaps is lack of data but where in fact many islands have relatively good networks of rainfall stations, the importance of such possibilities is stressed. Hence such studies can reach well beyond the purely descriptive stage and in fact supply basic empirical data.

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Acknowledgements

The basis of this study formed part of the Master of Arts thesis submitted by the author to the Department of Geography of the University of Natal, South Africa. The writer wishes to express his appreciation for the valuable discussion and suggestions given to this study by Dr. Charles Jordan, Dr. Noel E. LaSeur, Mr. E. G. Zipser, and Dr. Joanne Malkus, to members of the British Caribbean Meteorological Service for their help and to Miss Margaret Chaffee, Mrs. Nina Jane Petersen and Mrs. Mary Thayer for draughting and typing.

Table I. Mean Monthly Percentage Frequency of the 2000 foot Wind Direction with Average Velocities (kts) for each 30-degree Interval.

		271°-300°	301°-330°	331°-360°	1° - 30°	31°-60°	61°-90°	91°-120°	121°-150°	151°-180°	181°-210°	211°-240°	241°-270°	Mean Velocity
Jan.	Direction %f		1.6	1.6	3.3	4.8	83.9	4.8						11.4
	Average Speed		5.0	5	9.0	10.5	15.3	12.0						
Feb.	Dir. %f		1.8	3.6	8.9	10.7	58.9	16.1						12.2
	Av. Speed		5.0	5.0	6.0	12.3	16.0	13.7						
Mar.	Dir. %f					43.5	54.9	1.6						18.1
	Av. Speed					15.0	20.7	20.0						
Apr.	Dir. %f					11.7	53.3	35.0						15.0
	Av. Speed					12.5	17.0	14.7						
May	Dir. %f					1.6	59.7	37.1	1.6					13.4
	Av. Speed					8.0	16.7	16.7	9.0					
June	Dir. %f					10.0	48.3	36.7	5.0					12.4
	Av. Speed					9.0	14.0	14.3	12.5					
July	Dir. %f				4.8	9.7	50.0	29.0	6.5					10.7
	Av. Speed				4.3	12.3	13.3	13.7	8.0					
Aug.	Dir. %f		1.6	3.3	4.8	8.1	22.6	30.6	16.1	6.5	4.8	1.6		11.0
	Av. Speed		4.0	4.0	4.7	8.0	15.3	14.3	13.0	14.0	9	9		
Sept.	Dir. %f			5.0	8.3	5.0	11.6	30.0	15.0	6.7	6.7	6.7	5.0	8.8
	Av. Speed			5.0	4.3	8.0	13.7	12.3	10.3	4.3	8.0	8.0	6.0	
Oct.	Dir. %f			1.6	1.6	9.7	22.6	43.5	9.7	8.1	1.6	1.6		9.1
	Av. Speed			4.0	4.0	8.7	10.7	10.3	10.5	7.7	7.0	7.0		
Nov.	Dir. %f				13.3	18.3	18.3	40.0	8.4		1.7			11.0
	Av. Speed				8.0	14.3	11.7	13.0	9.5		8.0			
Dec.	Dir. %f				3.2	21.0	56.4	19.4						11.0
	Av. Speed				8.0	11.7	12.3	11.0						

Table 2 Percentage frequency of showers with the moisture level above 11,000 feet, true wind speeds between 10-20 knots and wind direction > and < than 90°.

STATION	NIGHT				DAY			
	6 pm - 12 midnight		12 midnight - 8 am		8 am - 12 noon		12 noon - 6 pm	
	WIND DIR. > 90°	WIND DIR. < 90°	WIND DIR. > 90°	WIND DIR. < 90°	WIND DIR. > 90°	WIND DIR. < 90°	WIND DIR. > 90°	WIND DIR. < 90°
MATURA	28	20	45	50	39	40	37	25
HOLLIS RES.	87	66	81	50	48	30	61	45
SPRING HILL	33	20	61	30	61	40	80	70
ORTINOLA	34	40	41	26	28	20	68	45
GOLF COURSE	7	5	11	10	37	45	63	70

Table 3 Percentage frequency of showers with the moisture level below 11,000 feet, the wind speed between 0-10 knots and wind direction > and < than 90°.

STATION	NIGHT				DAY			
	6 pm - 12 midnight		12 midnight - 8 am		8 am - 12 noon		12 noon - 6 pm	
	WIND DIR. >90°	WIND DIR. <90°	WIND DIR. >90°	WIND DIR. <90°	WIND DIR. >90°	WIND DIR. <90°	WIND DIR. >90°	WIND DIR. <90°
MATURA	48	8	11	8	0	8	25	8
HOLLIS RES.	17	0	28	25	23	8	28	8
SPRING HILL	5	8	5	8	17	8	62	25
ORTINOLA	17	17	5	8	0	8	45	33
GOLF COURSE	11	0	5	0	17	0	33	33
FORRES PARK	11	0	11	7	28	0	38	42
PENAL.	5	0	12	0	23	0	33	52

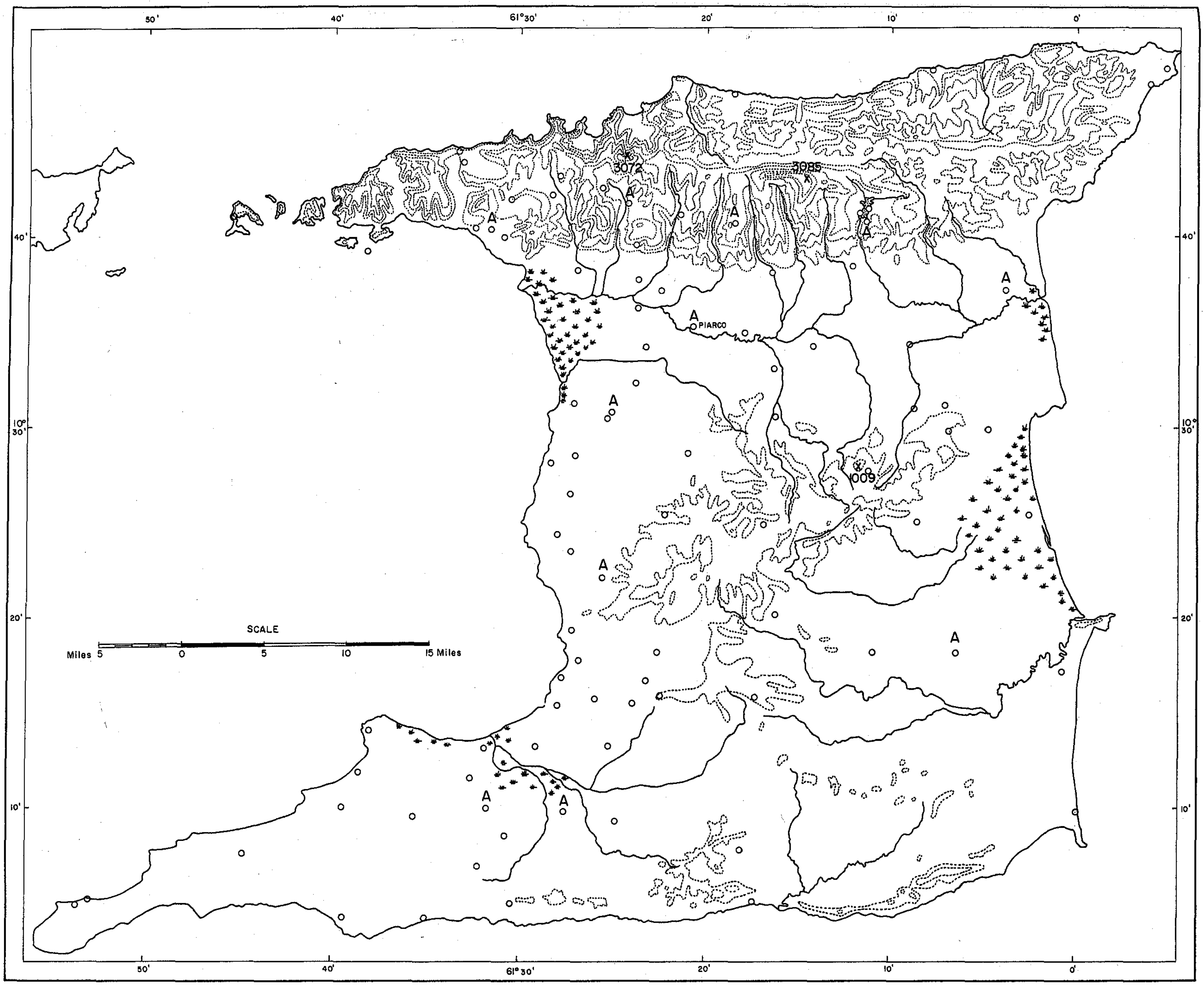

Figure 1. Island of Trinidad, W.I., showing physical features and location of ordinary (o) and automatic (A) rainfall gauges.

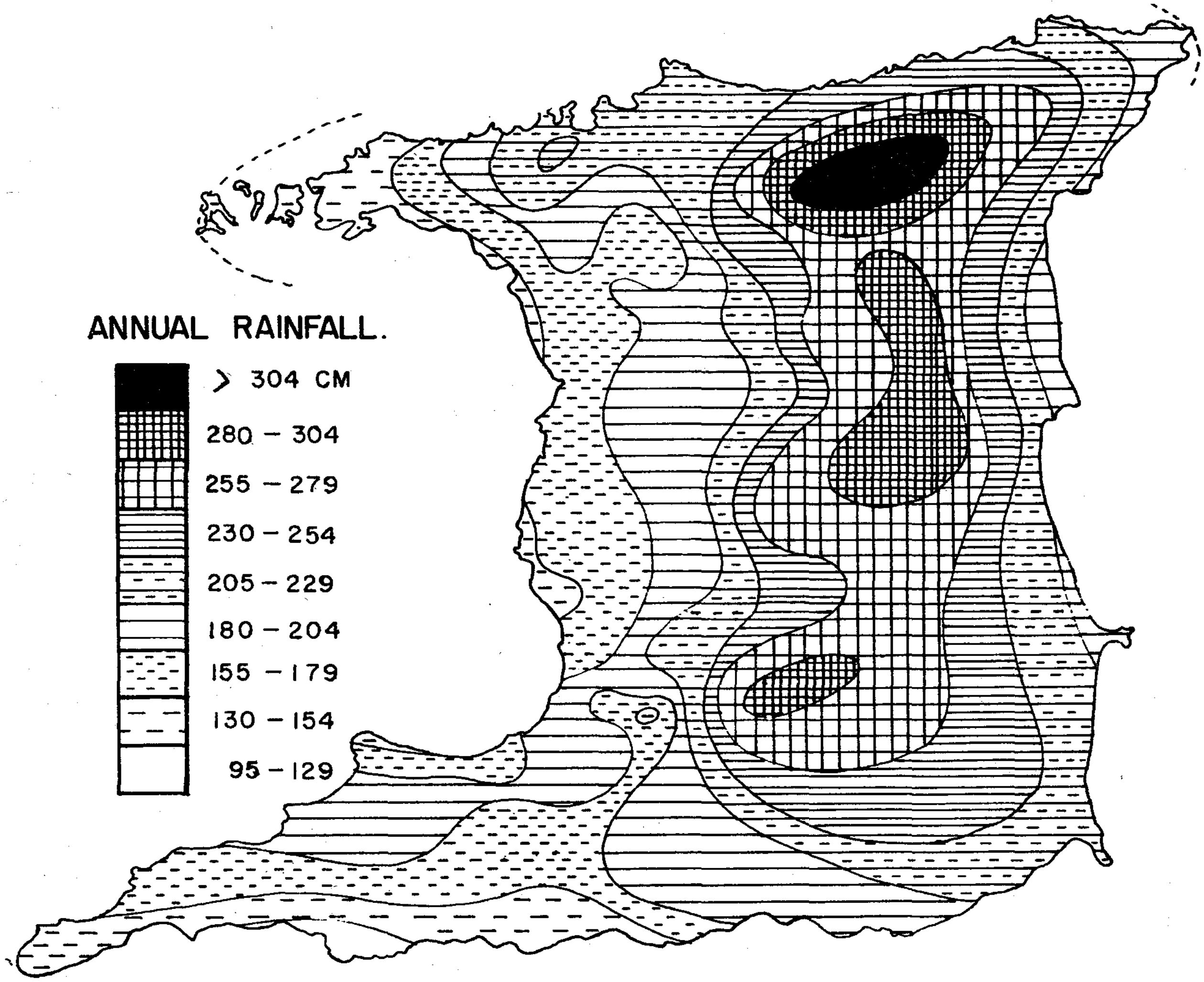

Figure 2. Mean Annual Rainfall

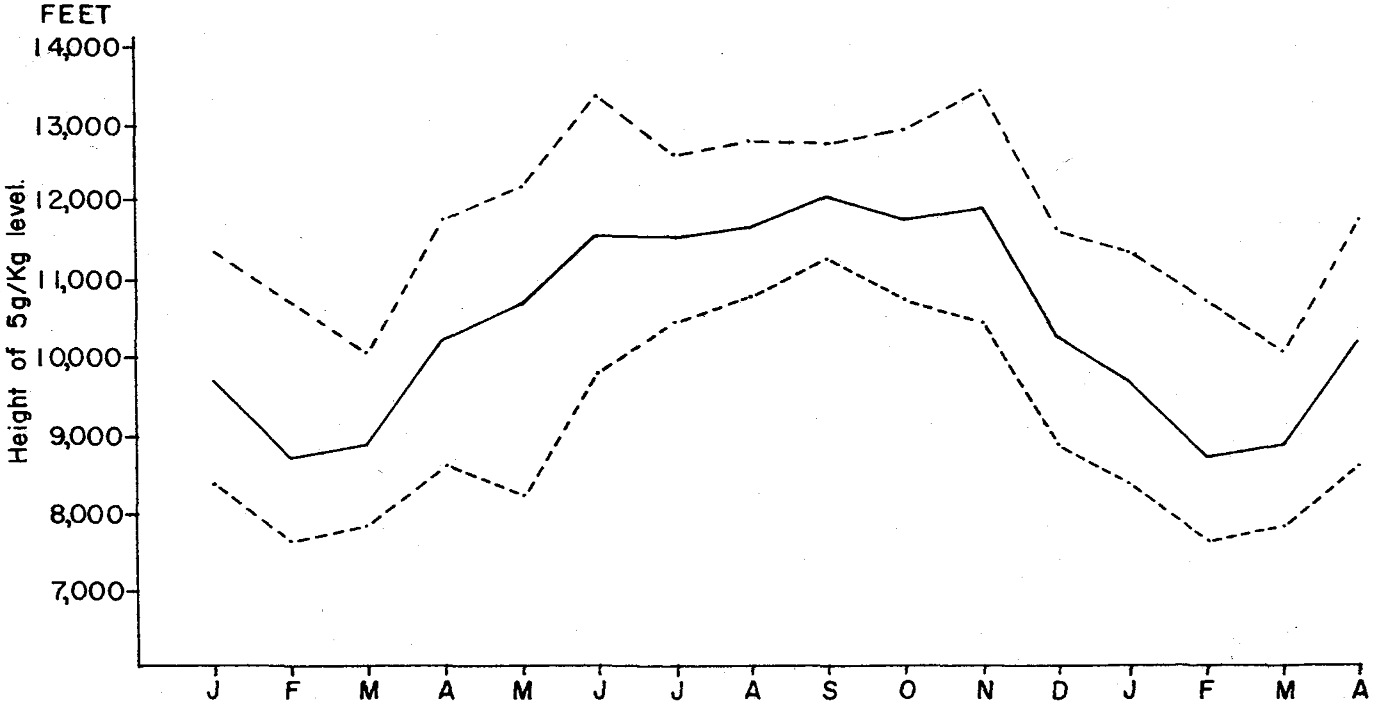

Figure 3. Mean height of moisture level (solid) and standard deviation (dashed).

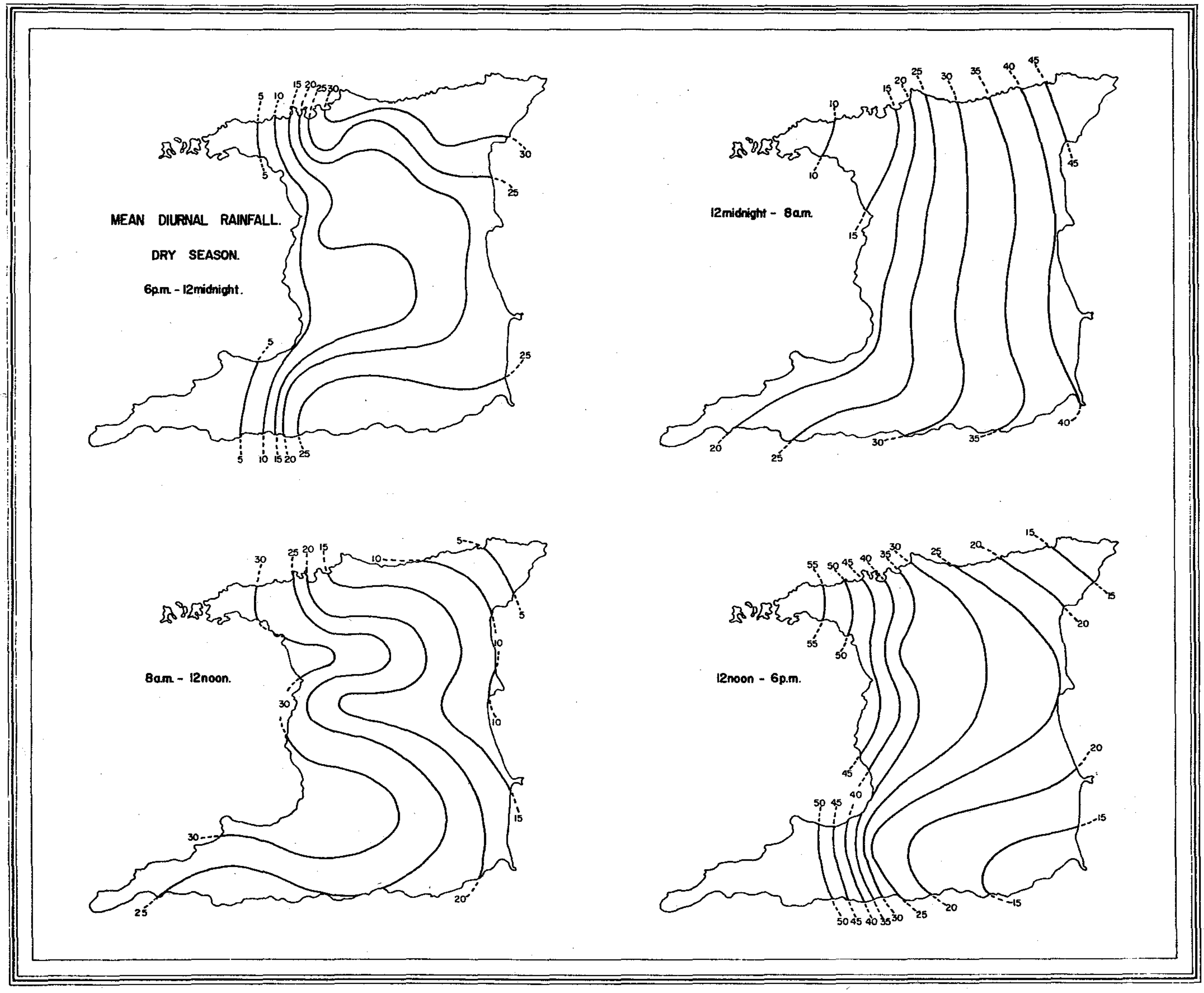

Figure 4. Mean diurnal rainfall as a percentage of the mean dry season rainfall, with isopleths at 5 per cent intervals.

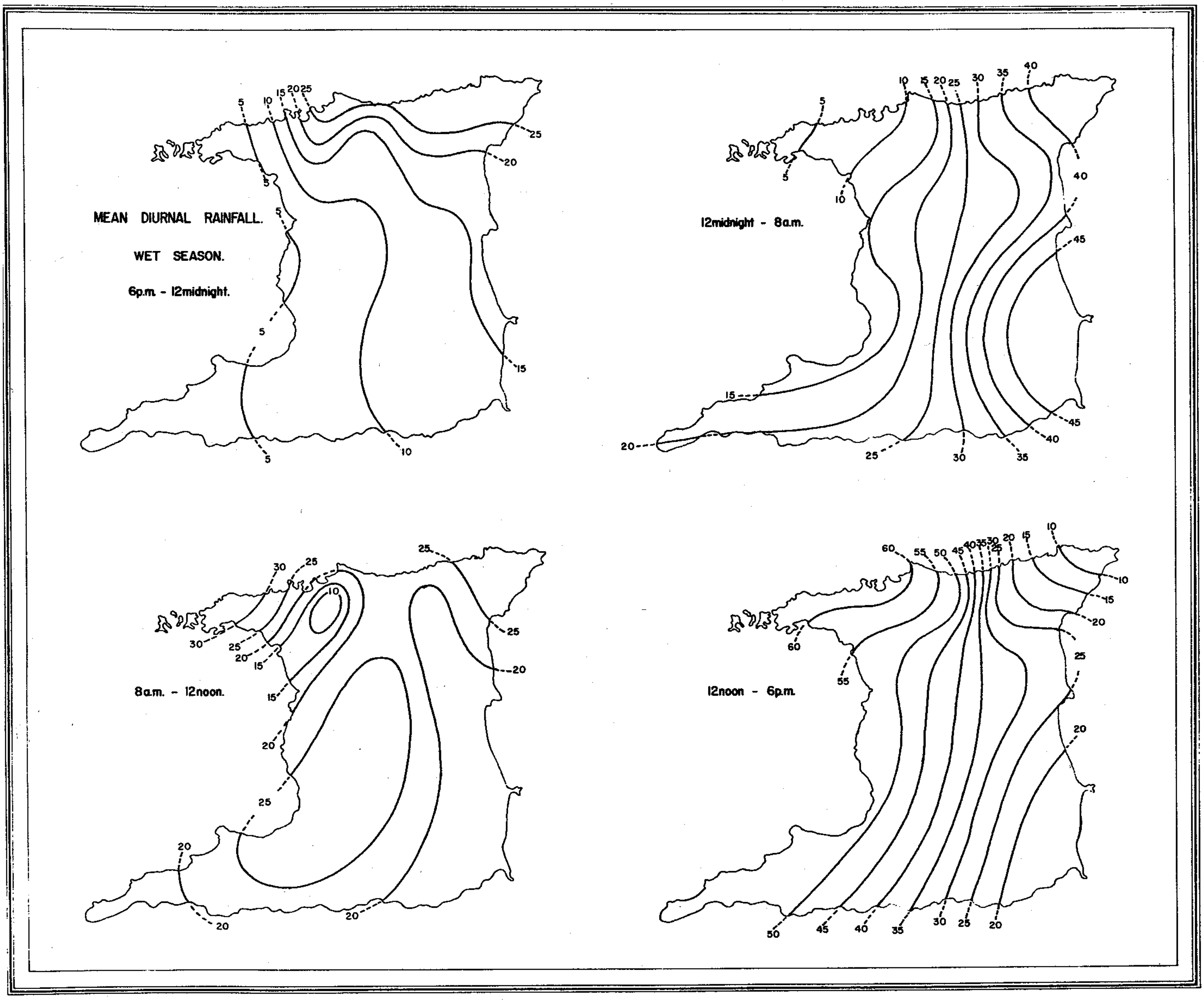

Figure 5. Mean diurnal rainfall as a percentage of the mean wet season rainfall, with isopleths at 5 per cent intervals.

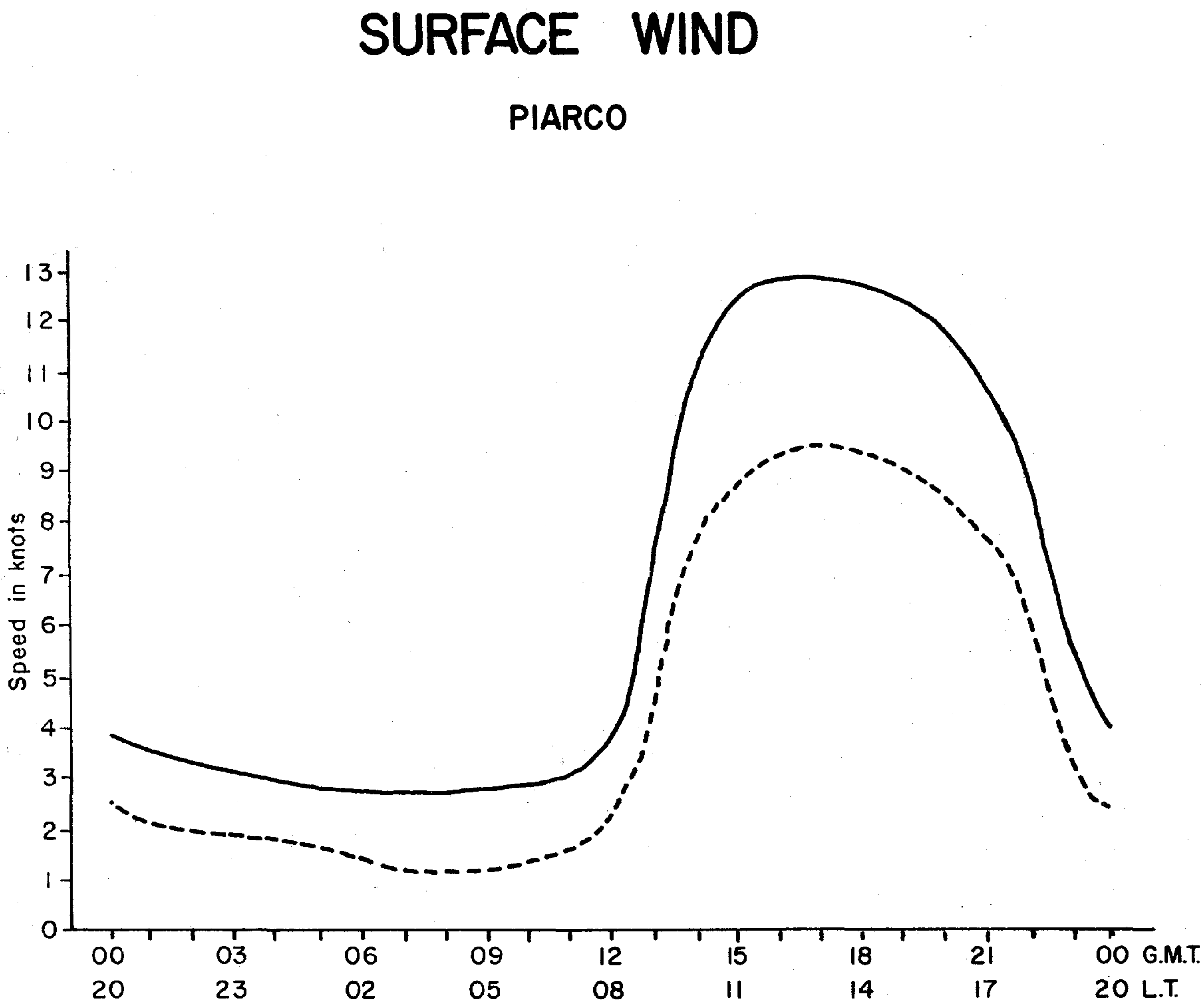

Figure 6. Diurnal variation of mean surface wind speed at Piarco regardless of direction. Dry season solid, wet season dashed.

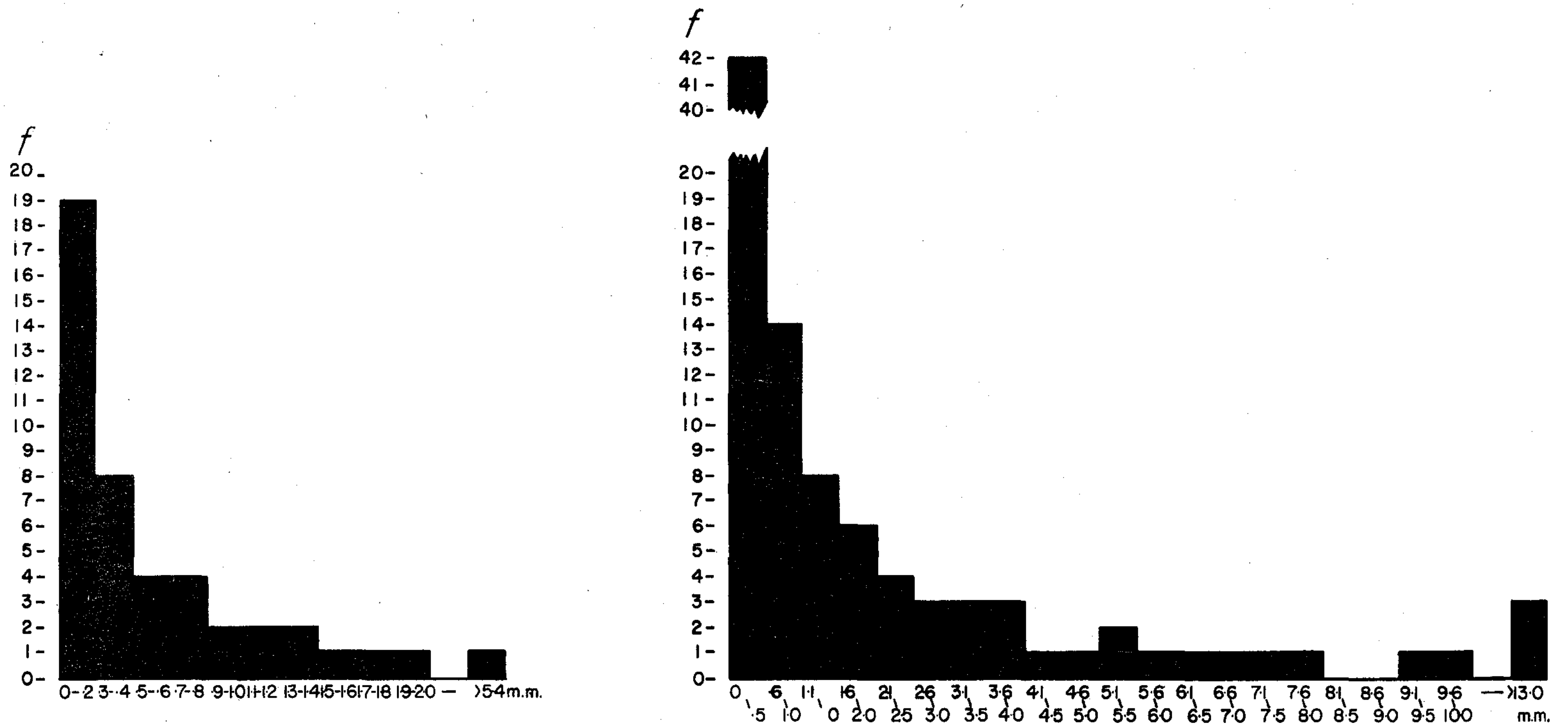

Figure 7a and 7b. Mean monthly frequency distribution of shower amounts
for (a) dry season (b) wet season

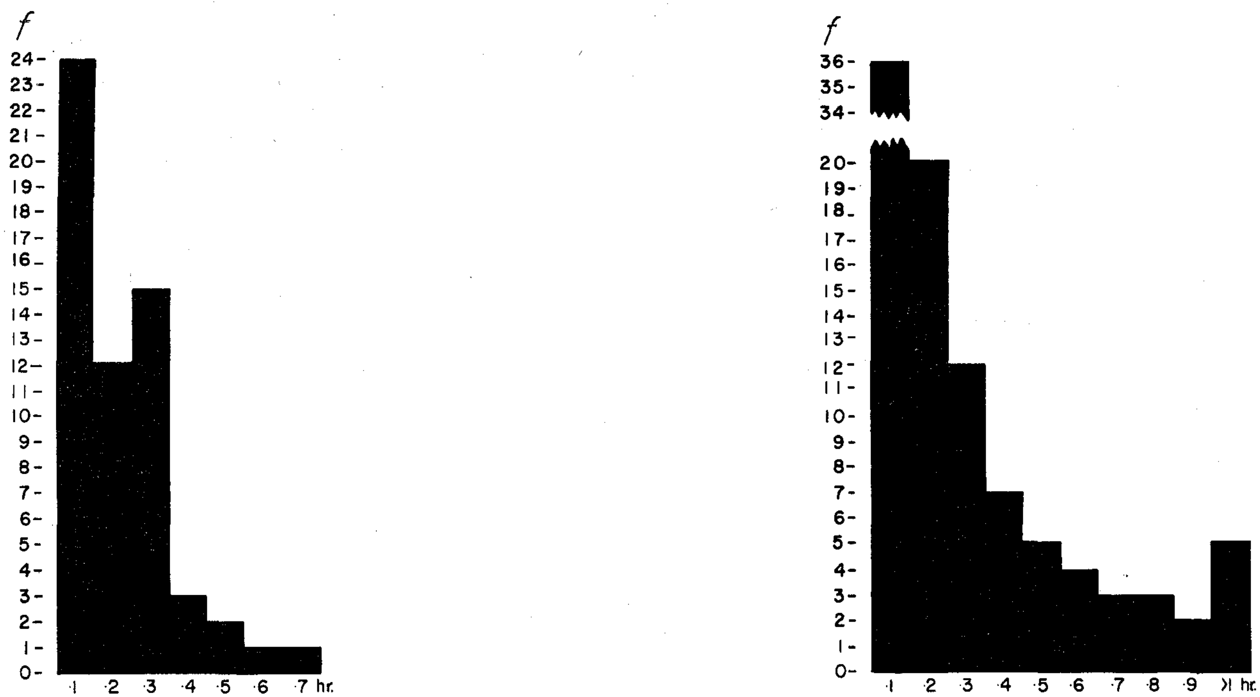

Figure 7c and 7d Mean monthly frequency distributions of shower duration for (c) dry season and (d) wet season.