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A COMPARISON OF RAINFALL IN THE EXCEPTIONALLY DRY YEAR 1963 AND AVERAGE CONDITIONS IN MALAYA

With 5 Figures, 2 Supplements (VI, VII) and 5 Tables

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Zusammenfassung: Ein Vergleich zwischen Niederschlägen während des Jahres 1963 und den Durchschnittsverhältnissen in Malaya.

Für die Beschreibung und Erklärung der Niederschlagsverhältnisse in Malaya wird fast immer auf langjährige Monatsmittel zurückgegriffen. Diese täuschen jedoch oft höhere Niederschläge vor als tatsächlich erwartet werden können, und unregelmäßig vorkommende Maxima und Minima werden schlecht oder gar nicht dargestellt. Auch ist nicht ersichtlich, wie weit die Niederschläge während individueller Monate vom Bilde der Durchschnittswerte abweichen.

Deshalb wurden die Niederschläge des Jahres 1963 für jeden Monat dargestellt und mit den Durchschnittsverhältnissen verglichen. Das Jahr 1963 war sehr trocken und daher für diesen Vergleich gut geeignet.

An sich aber genügen Niederschlagsziffern nicht um den Grad der Trockenheit darzustellen. Im 2. Teil des Aufsatzes wird daher ein Vergleich mit den Verdunstungsziffern durchgeführt, und an Hand von Wasserbilanzen werden die Wasserdefizite des Jahres 1963 berechnet. Dies zeigt, daß in den „immerfeuchten" Tropen Trockenzeiten von mehreren Monaten vorkommen können. Da diese Trockenzeiten nicht regelmäßig auftreten, werden sie in den üblichen, auf Mittelwerten beruhenden Darstellungen nicht aufgezeigt.

Descriptions of the rainfall conditions in Malaya [1]), as in many other parts of the world, are usually based on long-term averages (1). But the use of such averages has two serious disadvantages. Firstly, because every inch of rainfall received is given equal weight in the computation of the averages, these are often inflated by occasional heavy precipitation, even if this occurs very rarely. In Malaya, where the rainfall variability is high, this factor can cause differences up to 55% between the average rainfall figure and the median rainfall, i. e. the amount that can be expected to fall with a probability of 50% (2). Secondly, irregular changes in the amount of rainfall from a given month and the one following, and between years for the same months are largely obscured by averages. Even where the variability is indicated, it is usually expressed as a long-term value. It fails to show, therefore, how the actual rainfall conditions during an individual month differ from the average.

It is therefore clear that the conventional method of description does not always provide a satisfactory representation of the actual conditions. The present article tries to counter this drawback by comparing the actual rainfall conditions for the individual months of 1963 with the average conditions for the same months. The differences are described and explained. The usual explanations of rainfall in Malaya are then tested for their validity during 1963.

In the second part of the article the absolute rainfall figures for 1963 are compared with evaporation figures, computed for the same individual months. These latter figures give a reasonably accurate estimate of the amounts of precipitation needed under normal circumstances. To illustrate the importance of soil moisture storage in this respect, some water balances for the year 1963 are used. They indicate the size of the moisture deficit during this year, which are again compared to long-term averages. It is hoped that these descriptions will provide a more realistic basis for the further study of rainfall conditions in Malaya.

1. A Comparison of Absolute and Average Monthly Figures

Rainfall figures for 1963 were available for 142 stations (see Fig. 1 for location). They show a fair distribution over most of the country, with the exception of the sparsely settled highland areas. Consequently the accuracy of the interpolated values on the maps for these highland areas is much lower than elsewhere.

Since it was necessary to have long-term averages available for comparison, rainfall stations with long records of observation were selected wherever possible. About 80% (112) of all stations used had rainfall records of more than 10 years. The averages of the other stations based on records shorter than 10 years, were only used to decide on minor details in constructing the rainfall maps (Suppl. VI).

The year 1963 was the most recent for which precipitation figures were available at the time of preparing this paper. But it was also selected because it promised to illustrate some rather unusual conditions. Over large parts of Malaya the rainfall in 1963 was exceptionally low. Water

[1]) In this article, the term "Malaya" refers to both the Federation of Malaya and the State of Singapore.

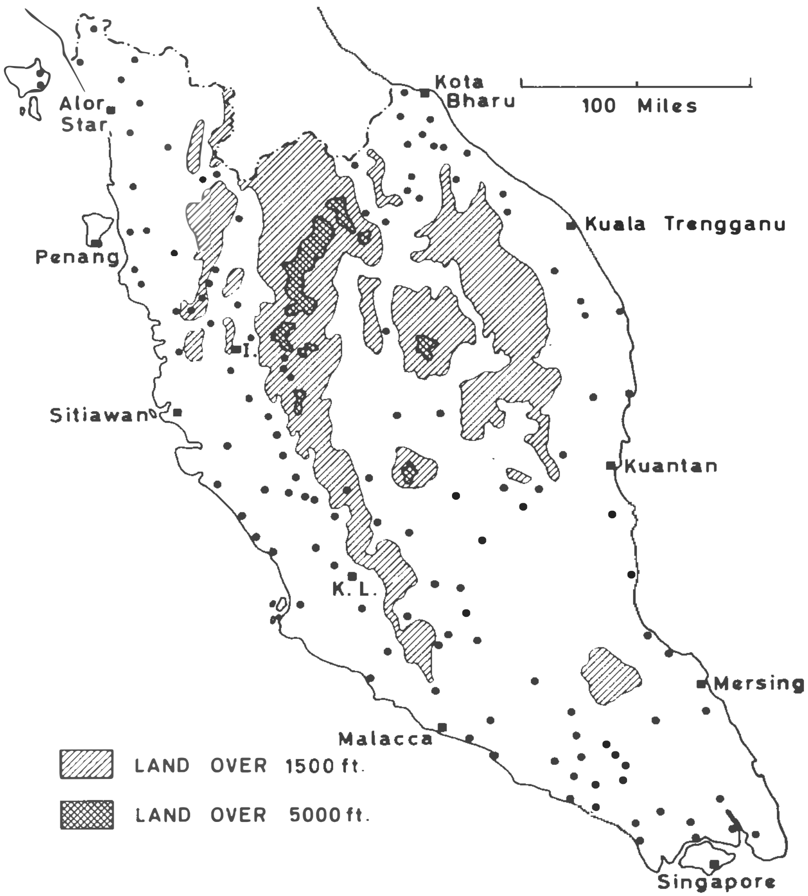

Fig. 1: Location of the rainfall stations of which the 1963 records were used. (Names are given for those meteorological stations where wind observations are recorded; K. L. = Kuala Lumpur, I. = Ipoh)

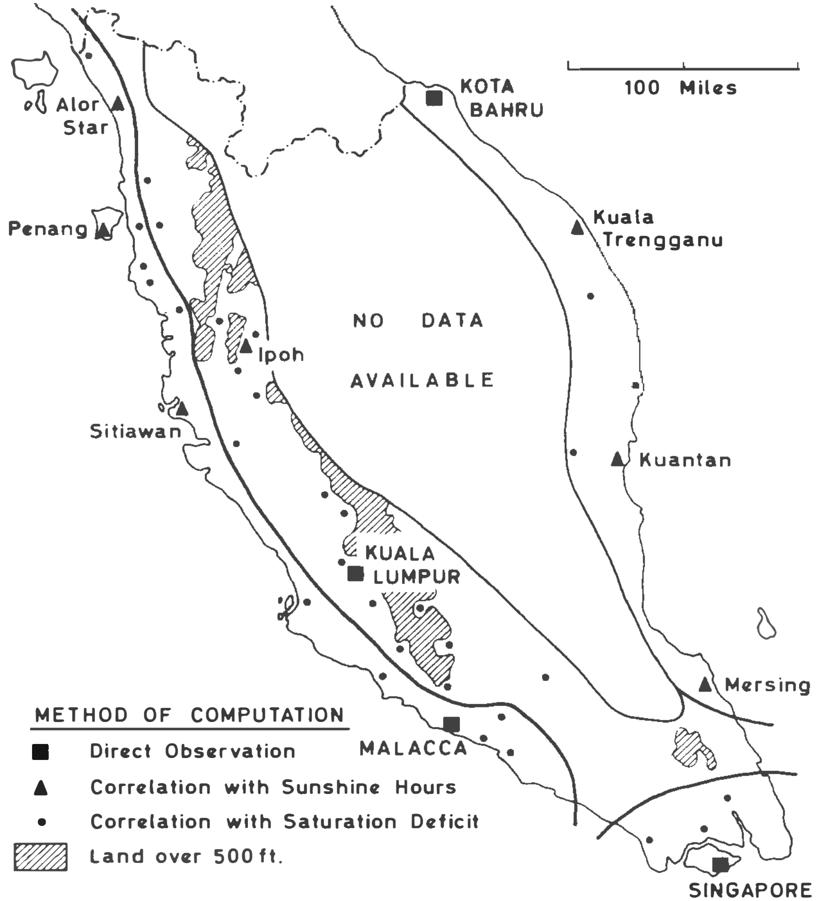

Fig. 4: Location of stations at which evaporation during 1963 was observed or computed, and method of computation

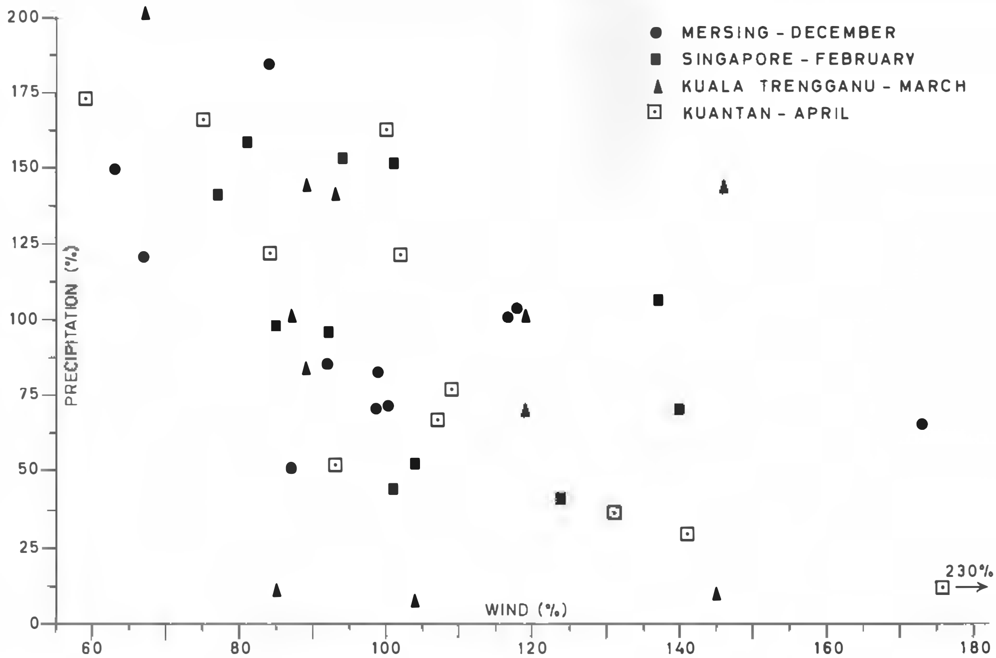

Fig. 2: Correlation between intensity of the North East monsoon wind and precipitation during the same month
Precipitation: in % of the average for the same month and station during the period 1953–1962 – Wind intensity: calculated by multiplying the average wind velocity of all winds from N, NE and E by the frequency of occurrence (in % of all observations) of these winds; expressed in % of the average value for the period 1953–1962

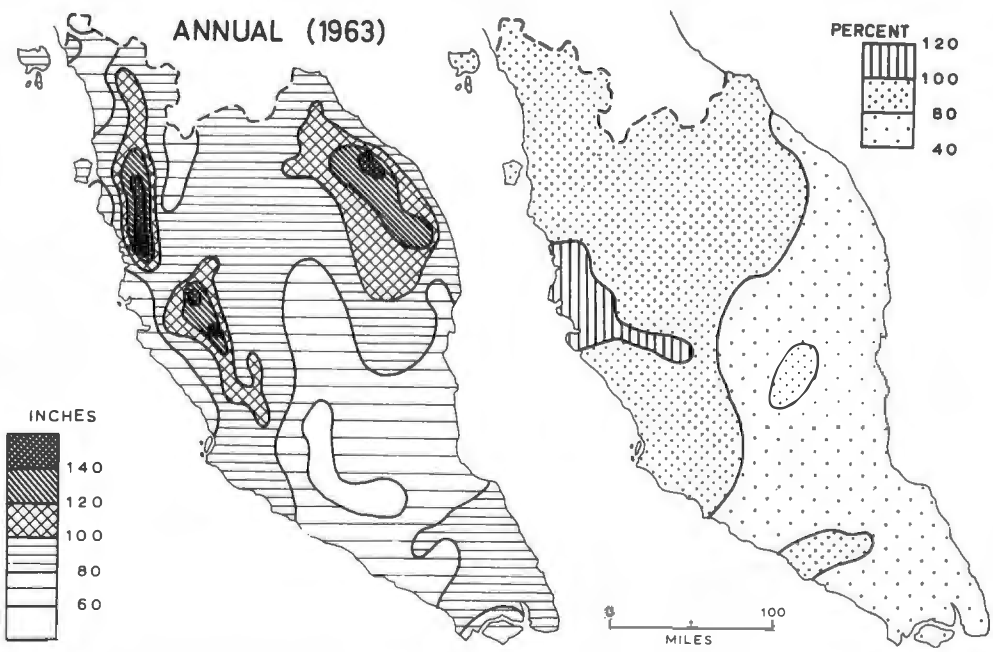

Fig. 3: Total annual precipitation during 1963 (right: in percent of average annual rainfall)

rationing had to be introduced in Singapore, Malacca and a number of other centres. Rice crops in Northwestern Malaya suffered heavy losses from long droughts.

The maps (Suppl. VI) show first, for each month of 1963, the absolute amount of rainfall received and second, these amounts expressed as a percentage of the long-term average rainfall for the same month: the former is shown on the left and the latter to the right of each map. To avoid the impression of an unwarranted accuracy, isohyet intervals are rather large.

An important part of the precipitation in Malaya is due to isolated convectional showers, which bring heavy rainfall to only small areas (3). On rainfall maps based on averages these convectional showers will be more or less evenly distributed over large areas, but maps for one single individual month often show very large differences in amounts of rainfall received over short distances. All exceptionally high rainfall values, recorded at only one station and not at its neighbouring stations, were therefore disregarded as a basis of construction of the isohyets. The maps can be considered as generalizations, on which a considerable amount of detail has been suppressed.

For a general comparison with average conditions the maps by Dale (4) were used. A large number of souces were used for information about the general circulation over South East Asia (5). However, descriptions and maps of an "average" circulation are of limited value for the explanation of rainfall in Malaya. This is because one of the most important characteristics of the general circulation in this part of the world is the rapidity and extent of changes in the position of air-stream boundaries. To establish the actual conditions during 1963, daily weather maps were examined.

January

During this month the circulation over Malaya is dominated by the North East monsoon, which usually commences its influence in November or December [2]). Rainfall is consequently highest along the East coast, especially in the northern parts, where orographic lifting is strongest. The Western parts of Malaya, in the rain-shadow of the Main Range, are relatively dry (see Fig. 1). January 1963 (Suppl. VI) conformed quite closely to this pattern. Weather maps for this month revealed that the position of the air-stream boundaries was more or less normal, that is far to the South and the West of Malaya (6). The North East monsoon was about average in terms of frequency of wind direction and force (Table 1). Rainfall during January 1963 was normal and only small parts of Malaya showed a departure of more than 60% from the average rainfall for this month.

[2]) The term "monsoon" is used here in its original meaning of "regional wind system" and not, as locally in Malaya, in the sense of an index of precipitation. See P. PEDELABORDE – Les Moussons, Paris, 1958, p. 9–10.

February

There is a chance of about one in four that February will simply bring a continuation of the January conditions, but usually this month is much drier than January (8). The full extent of this sharp decrease of precipitation is not shown by long-term averages, as it comes irregularly from year to year, sometimes as early as January, other years as late as March. But the 1963 conditions illustrate this decrease of precipitation very well: at some stations in East Malaya the amount of rainfall during February 1963 was less than 10% of that during January, and in all parts of the country February was much drier than January. This substantial decrease, compared to January 1963, cannot be attributed to a change in the wind intensity of the North East monsoon, which continued to blow with about the same force (Table 1). The explanation of the decrease in precipitation must therefore be connected with a change in the character of the air-masses which the North East monsoon brings to Malaya. Two factors are of importance in this respect: convergence or divergence within the air-stream and the humidifying action of the South China Sea.

Convergence or divergence within the air-stream of the North East monsoon is related to an upper-air anticyclonic cell over Thailand (9). This cell develops during November and December and it causes a convergence of surface air-streams to the East of Malaya, which results in an increased instability of the air-masses that reach Malaya during these months. The anticyclone starts to decay usually during January, but in some years much later. It is replaced by a shallow surface low over Thailand, caused by increased insolation. Together with a slightly higher pressure further East, this low gives rise to a divergence in the air-streams of the North East monsoon (10). The stabilization of the air-masses is usually experienced during February in Malaya, when these air-masses do not even produce much precipitation when they are forced to rise orographically. In 1963 the stationary surface low over Thailand appeared in the beginning of February and remained active, with some interruptions, until the end of April, being especially intensive during this last month.

The humidifying action of the South China Sea depends in part on the water surface temperatures. These reach their annual maximum temperatures during September. Then a cool current from the North slowly extends its influence southwards and the lowest water temperatures are reached in February. These are, in Hong Kong about 16° Centigrade, in the South (20° N.

Table 1
Intensity of the Northeast Monsoon (7)

	Wind Direction (Frequency of occurrence of all observations from N, NE and E in % of total number of observations)			*Average Wind Velocity* (for all winds from N, NE and E, in meters/sec.)		
	1953–1962*)		1963	1953–1962*)		1963
January	Maximum	Average		Maximum	Average	
Kota Bharu	75	68	70	4.7	3.8	4.0
Kuala Trengganu	87	72	76	4.1	3.2	3.5
Kuantan	91	77	86	3.8	3.0	3.4
Mersing	97	83	91	7.0	5.9	6.0
Singapore	94	77	94	3.2	2.4	2.8
February						
Kota Bharu	73	62	78	4.2	3.8	4.4
Kuala Trengganu	76	64	88	3.1	2.7	2.7
Kuantan	85	71	92	3.7	3.0	3.5
Mersing	91	84	97	6.9	5.3	6.7
Singapore	82	73	89	3.1	2.5	2.8
March						
Kota Bharu	63	51	70	3.9	3.5	4.0
Kuala Trengganu	63	54	74	3.0	2.4	2.6
Kuantan	65	55	77	3.4	3.0	3.4
Mersing	76	70	89	4.8	3.8	5.4
Singapore	65	52	87	2.6	2.2	2.6
April						
Kota Bharu	48	40	58	3.6	3.1	4.0
Kuala Trengganu	48	39	56	2.8	2.1	2.8
Kuantan	46	37	60	3.2	2.5	3.6
Mersing	58	39	72	3.8	3.0	4.3
Singapore	43	26	65	1.9	1.6	2.5

*) For Kota Bharu records were only available for the period 1956–1962.

120° E). around 24° Centigrade. This is, in Hong Kong about 6°, in the South approximately 11° Centigrade less than during September (11). The decrease of the water temperatures is, of course, a very gradual process and it does not explain the rather sudden decrease of precipitation in Malaya in February. Water temperatures during 1963 in Hong Kong were about average (12) and the extreme dryness of February 1963 and the following months cannot satisfactorily be explained by this factor. But the humidifying action of the South China Sea also depends on the rapidity of the journey of the air-masses over this stretch of water. If the progression is fast, only relatively shallow layers of surface air will be made more humid. Fig. 2 demonstrates that a strong monsoon wind usually brings less precipitation to Eastern Malaya than a weak one and that this correlation exists during all months of the North East monsoon season. The same interrelation occurs in other parts of Malaya during the same period, but in these sectors wind figures are more complicated because of the stronger influence of local winds. In February 1963 the North East monsoon was exceptionally strong (Table 1).

February 1963 was a very dry month: almost everywhere in Malaya the precepitation remained well below the average (Suppl. VI). In some parts of Northwestern Malaya no rain fell during the whole month, which is surely a very rare occurrence. There are two main reasons for this dryness: the early activity of the surface low over Thailand and the unusual intensity of the North East monsoon.

March

During this month the circulation over Malaya is usually still dominated by the North East monsoon, although its intensity is much lower than in February (Table 1). This seems to be the main reason why March is normally wetter than February everywhere in Malaya. But in March 1963 the monsoon was exceptionally intensive and the intermittent surface low over Thailand was quite active. These two facts explain why March 1963 showed a continuation of the very dry conditions of February. Only in Northwestern Malaya a slight increase of precipitation compared to February was recorded.

April

From this month onwards the North East

monsoon gradually loses its influence on the circulation over Malaya. Average wind figures for stations on the East coast of Malaya still show relatively high frequencies of occurrence for winds from North, Northeast and East, but a large part of these winds are sea-breezes (Table 1).

In East Malaya, April is usually drier than March. This is caused by the increased effect of the surface low over Thailand, which in this month becomes very active. Also, the air-masses of the last phases of the North East monsoon are quite stable aloft. Their origin is now a high pressure area over the North Pacific and the North East monsoon is mostly an extension of the North Pacific trade winds, (13).

But in West Malaya April usually brings more precipitation than March. Here the main source of the rainfall is the air-stream boundary between the westerlies from the Indian Ocean and the retreating North East monsoon. The average position of this air-stream boundary during April is over the Straits of Malacca. But is moves over considerable distances and the size of the areas to which it brings increased rainfall depends on its highly variable slope (14).

The circumstances during April 1963 were, however, quite different. The North East monsoon continued to dominate the circulation over Malaya (Table 1). The weather maps for this month show that the air-stream boundary between westerlies and North East monsoon was still far to the West of Malaya. This is illustrated by the wind figures for 4 stations in West Malaya (Table 2). The table indicates that the frequency of occurrence of winds from North, North East and East was far above the average. But the calms, which are normally predominating near the air-stream boundary, were less numerous than usually. At the same time, weather maps for this month revealed that the surface low over Thailand was very intensive. The North East monsoon carried therefore quite stable air masses to Malaya.

The result of all these factors was an exceptionally dry month in the whole of Malaya (Suppl. VI). In large parts of the country the precipitation was less than 20% of the average for this month.

May–September

During these five months the South West monsoon prevails over Malaya, but it never dominates the circulation to the same extent as the North East monsoon does from December to February. In these months, wind velocities are lower and wind directions are more variable than during the North East monsoon season. Many

Table 2

Wind Figures for April in West Malaya (7)

	Frequency of occurrence (in % of the total number of observations)			
	All winds from North, North East and East		*Calms*	
	Average for 1953–1962	1963	Average for 1953–1962	1963
April				
Alor Star	39	62	28	13
Penang	28	36	25	21
Sitiawan	21	32	43	32
Malacca	44	58	20	16

calms occur and at coastal stations wind statistics are strongly affected by land and sea breezes (Table 3).

This is usually a relatively dry season in Malaya. The main reason is the sheltering effect of the mountain ranges of Sumatra. This influence is felt very strongly in the central latitudes of Malaya, especially in the West, where the South West monsoon crosses only over the narrow Straits of Malacca. But further North, were the extents of the Straits of Malacca are much broader, the effect is less clear. In the Southern parts of Malaya (including Singapore) too there is very little impact of this sheltering effect. This is because here the South West monsoon frequently has a southerly or south-easterly direction, thereby parallelling the mountains of Sumatra (15). Therefore the central latitudes of Malaya are usually the driest part of the country during these months.

The South West monsoon shows only a limited amount of variation in wind force and direction from year to year. Statistics for the last eleven years showed no correlation between its differences in intensity and the variation of rainfall in Malaya. In this season, the variation of the precipitation seems to be related rather to three factors: the air-stream boundary, the local disturbances and the local winds.

The air-stream boundary which is of greatest importance for rainfall in Malaya during these five months is not the one between the retreating North East monsoon and the advancing South West monsoon. This particular air-stream boundary moves relatively fast over Malaya, usually during April, and has no importance after that as it has left the area completely. The important air-stream boundary is the one between the south-easterlies from Indonesia, which become south-westerlies at a latitude of about 3° North, and the westerlies from the Indian Ocean. This air-stream boundary lies over Malaya during a major

Table 3
Intensity of the South West Monsoon (7)

	Wind Direction (Frequency of occurrence of all observations from S, SW and W, in % of total number of observations)			*Average Wind Velocity* (for all winds from S, SW and W, in metres/sec.)			*Calms* (frequency of occurrence, in % of total number of observations)	
	1953–1962		1963	1953–1962		1963	1953–1962	1963
	Maximum	Average		Maximum	Average		Average	
May								
Alor Star	35	29	25	1.7	1.4	1.8	30	23
Sitiawan	28	23	30	3.1	2.8	2.7	43	26
Malacca	37	34	28	3.5	3.1	3.6	27	18
June								
Alor Star	39	32	34	1.7	1.5	1.9	29	29
Sitiawan	35	26	26	3.0	2.8	2.7	46	31
Malacca	40	36	27	3.5	3.1	3.3	28	43
July								
Alor Star	39	33	38	1.8	1.5	1.6	27	31
Sitiawan	29	25	34	3.5	3.0	3.0	41	29
Malacca	41	36	*)	3.5	3.1	*)	28	*)
August								
Alor Star	38	33	32	1.6	1.5	1.6	29	30
Sitiawan	28	24	25	3.4	2.9	2.8	40	27
Malacca	44	37	31	3.4	3.1	2.8	24	52
September								
Alor Star	36	33	36	1.5	1.4	1.4	31	16
Sitiawan	26	24	25	3.4	2.8	2.6	38	24
Malacca	40	36	29	3.7	3.2	3.1	24	50

*) Records for July 1963 at Malacca were not available.

part of these five months (16). It is extremely variabel in location, often moving hundreds of miles in a few days. On daily weather maps for this season it can usually be located quite easily. The air-stream boundary is always associated with an increased tendency for precipitation. Because of its relatively gentle slope the areas which come under its direct influence are usually rather broad.

With the South West monsoon travel many disturbances in the form of depressions or squalls (17). They can bring large amounts of rainfall, but mainly when they are combined with other factors, such as orographic lifting, convection or the air-stream boundary. A very intensive type of disturbances, locally called "Sumatra's", occur along the South West coastal regions of Malaya. They are an important source of rainfall during the season of the South West monsoon (18).

The local winds which are of significance for rainfall in Malaya are the land and sea breezes and, to a minor degree, some anabatic and katabatic winds. During the South West monsoon season these local winds develop noticeably because of the low wind velocities of the general circulation. They are responsible for a large part of the precipitation in Malaya during this period (19).

There was nothing very remarkable about the season of May to September 1963. The precipitation during these months showed only relatively small variations from the average (Suppl. VI). These variations were generally well within the normal variability limits for these months.

The high precipitation in West Malaya during May 1963 was related to the air-stream boundary between North East and South West monsoons. This boundary, which normally passes over Malaya during April was delayed in 1963 because of the abnormally high intensity of the North East monsoon. It remained almost stationary over West Malaya for about 10 days in May 1963. It then crossed over the Main Range and disappeared quickly from Malaya.

It was impossible to establish any meaningful correlations between rainfall figures and air-stream boundaries or disturbances for the rest of this period. This was due to the great changeability in location of these factors.

October

This month is usually a period of transition. The South West monsoon still prevails over

Table 4
Intensity of the Northeast Monsoon (7)

	Wind Direction (Frequency of occurrence of all observations from N, NE and E, in % of total number of observations)			Average Wind Velocity (for all winds from N, NE and E, in metres/sec.)		
	1953–1962*)		1963	1953–1962*)		1963
	Maximum	Average		Maximum	Average	
October						
Kota Bharu	29	25	28	3.1	2.5	2.7
Kuala Trengganu	29	26	25	2.1	1.9	1.6
Kuantan	30	21	24	2.4	2.1	2.4
Mersing	24	19	21	3.5	2.9	2.9
Singapore	17	11	16	1.5	1.2	1.6
November						
Kota Bharu	46	37	40	3.3	3.0	2.6
Kuala Trengganu	76	36	36	3.3	2.3	1.7
Kuantan	55	41	40	2.9	2.3	2.4
Mersing	50	35	36	4.9	3.5	3.3
Singapore	45	27	28	1.9	1.6	1.4
December						
Kota Bharu	68	55	51	3.8	3.4	2.9
Kuala Trengganu	76	62	60	3.5	3.0	2.3
Kuantan	83	68	64	3.0	2.6	3.3
Mersing	93	67	60	6.0	4.8	5.4
Singapore	88	60	59	2.4	1.9	1.7

*) For Kota Bharu records were only available for the period 1956–1962.

Malaya, but it is very weak and often interrupted. Wind velocities are low and wind directions highly variable. Wind statistics for this month reflect mainly the influence of local factors and at coastal stations the land and sea breezes completely dominate the picture (Table 4). The air-stream boundary between the retreating South West monsoon and the slowly advancing North East monsoon usually still lies far to the North East of Malaya (20). Rainfall during this month is almost entirely related to local factors, such as convection and local winds and because of the general instability of the atmosphere October usually brings large amounts of rainfall to all parts of Malaya.

October 1963 was no exception. Especially West Malaya was quite wet, and this was largely due to a weak, but almost static air-stream boundary which remained over this part of the country for about 20 days.

N o v e m b e r

This month is often taken as the first month of the North East monsoon season, but this is, strictly speaking, only true for North Malaya. The North East monsoon progresses slowly from North East to South West, but this movement is often interrupted or even temporarily reversed. The North East monsoon did not become effective until December for five out of ten years (1953–1962) in Singapore, but only twice during the same period in North Malaya (Kuala Trengganu, Kuantan). November therefore usually shows a marked increase of precipitation, compared to October, in the northern parts of Malaya, but in the South the increase is very modest (21).

The wettest part of Malaya in November is the North East. This is related to the position of the air-stream boundary between the retreating South West and the advancing North East monsoons, which is usually located over this part of the country during November. It becomes increasingly important as a cause of widespread heavy rainfall with the intensification of the North East monsoon.

But in November 1963 a different situation dominated the weather maps. The air-stream boundary remained over Eastern Malaya only for the first ten days of the month and then moved rapidly to the Straits of Malacca and Western Malaya, where it remained static almost until the end of the month. The result was that Western Malaya was much wetter than usual. In Eastern Malaya on the other hand, the nonprevalence of the air-stream boundary caused a relatively dry month. The North East monsoon had started quite early, but it remained rather weak and its wind velocities were well below average (Table 4). It was stated before that a weak North East monsoon usually brings more precipitation to Malaya than a strong one, but this effect is not very clear during the very beginning of the monsoon, when the air-stream boundary is a much more important cause of rainfall.

December

During this month the circulation over Malaya is again completely controlled by the North East monsoon. The monsoon is usually not yet as strongly developed as in January (compare Tables 4 and 1). Along the East Coast of Malaya, where the effects of the North East monsoon are felt most strongly, the wettest month of the year is the first month with a well established monsoon. In the North (Kota Bharu, Kuala Trengganu) it is November, in the central latitudes (Kuantan, Mersing) December and in the extreme South (Singapore) January is the month with the highest rainfall. In a picture, based on long-term averages, these differences are largely obscured because of the strong variations from year to year in actual amounts of rainfall received, but they are clearly shown in figures for median rainfall (22).

In the Central and Western parts of Malaya December is usually drier than October and November. This is caused by the almost complete disappearance from the country of the air-stream boundary. Also, the rain-shadow effect of the Main Range becomes more pronounced as the North East monsoon develops strength.

December 1963 was rather dry (Suppl. VI). The main reason for this was the almost complete absence during the second half of the month of any air-stream boundaries, disturbances and other rain-bringing factors. The rainfall was almost everywhere less than during November, the only exception to this was the South East of Malaya, where the North Neast monsoon did not really start until December. The intensity of the monsoon was about average (Table 4).

Summary

Although the pictorial mosaic of annual rainfall for 1963 (Fig. 3) shows a striking similarity visually with the mosaic of average annual rainfall in terms of a pattern of distribution, the total amounts recorded in 1963 were generally well below normal. This is particularly the case in the southern and eastern parts of Malaya, where the 1963 rainfall was below 80 % of the average. In the Northern and Western parts of the country the 1963 rainfall was much nearer to normal (Fig. 3). The reason for this clear division lies in the extremely dry first four months of the year. In the South and East these months usually bring a major part of the total annual rainfall: Kuala Trengganu 33 %, Kuantan 34 %, Mersing 34 %, Singapore 34 %. But in the North and West this period is relatively dry anyway: Kota Bharu 22 %, Alor Star 21 %, Malacca 23 %, and the loss of rainfall during these months did not make great difference in the annual total. Moreover, May, July and September 1963 were rather wet months in Western Malaya.

2. Rainfall and Evaporation during 1963

Precipitation figures alone cannot very well indicate the dryness of a place. Some comparison is needed with water requirements. In a former article it was shown that evaporation figures provide a good estimate of the water needs in Malaya (23). Evaporation is only recorded at four stations in Malaya, but it can be computed with a reasonable degree of accuracy for the other parts of the country on the basis of close correlations with other meteorological data (24). Fig. 4 shows the stations at which evaporation was observed or computed for 1963. The four stations with direct observations were used as base stations for computation in the indicated parts of Malaya. For seven stations this computation was done on the basis of the correlation of evaporation with the actual hours of sunshine, which method gives the best results. But for the other stations, where actual hours of sunshine are not recorded, the correlation of evaporation with the saturation deficit was used, the saturation deficit being calculated from temperature and humidity records. The use of two different methods of computation excluded any possible bias, inherent in either method, as far as possible. Because of the complete lack of data, no evaporation can be computed for the central parts of Malaya.

The evaporation during 1963, as shown on the maps (Suppl. VII A), can be assumed to have an accuracy of about 1/2 inch near the four base stations and of about one inch for the most remote parts of the country, as North West Malaya. The maps show that there exists a clear negative correlation between precipitation and evaporation: dry months, for instance March and April, have much higher evaporation figures than wet months, such as November and December. The reasons for this is clear: rainfall brings with it more cloudiness and thereby lower temperatures, and a higher relative humidity. All these factors reduce evaporation. The very high evaporation values for March, April and May 1963 are, of course, a direct result of the extremely dry conditions during these months.

The Föhn effect of the Main Range is clearly visible on the evaporation maps for January and February 1963, with high values in West Malaya.

But this effect disappeared during March and April. Although the monsoon circulation was still strong, the air-masses of the North East monsoon during these two months were apparently so stable that evaporation was higher on the windward side of the mountains (East Malaya), where the wind velocities were higher than on the leeward side. During the South West monsoon season (May-September) the Föhn effect was very clear, resulting in higher evaporation figures in East Malaya.

Generally, the distribution pattern of evaporation during 1963 was similar to that of the long-term averages (25). However, this comparison is of limited importance, since the long-term averages of evaporation in Malaya were based on only 5 years of observation.

Suppl. VII B show the results of a comparison between rainfall and evaporation during 1963. To avoid an impression of accuracy which would be unrealistic in view of the computation and interpolation of the figures, the class interval for water surpluses and deficits was made relatively large, namely two inches.

During the North East monsoon season, which in 1963 lasted until the end of April, water deficits predominated (Suppl. VII B). While January brought the normal water surplus to East Malaya, the next three months all brought significant water deficits to this part of the country, which is very unusual. But even more unusual are the large water deficits in the western parts of Malaya during March and April. On the basis of records for about 30 years, the probability of this happening can be estimated as less than 20% (26). These maps are a good illustration of the exceptionally dry conditions during this season.

The next four months brought more normal conditions. In West Malaya the water surpluses are interrupted by small deficits, but in East Malaya the deficits prevail, as is usually the case during this season. Only August 1963 brought a water surplus to East Malaya. This is undoubtedly related to the evening rainfall maximum, as described by RAMAGE (27) and this also explains why, during August, the East coast had high figures both for the precipitation and for evaporation. The rainfall was mainly concentrated during the night and did not interfere with the evaporation, which always occurs mainly during the day.

The last four months of the year 1963 brought the usual large water surpluses in all parts of Malaya. Only South Malaya and Singapore had to wait until November for the end of the long drought, whereas in all other parts of the country September had brought an end to it.

3. Water storage and monthly water balance

These maps (Suppl. VII B) fail to show, however, to what extent water surpluses in one month can compensate for deficits in following months. This form of compensation is largely carried out by water stored in the soil. It is impossible to calculate this factor for large areas, but its influence can be shown in the form of water balances for individual stations. Water balances for some of the most important towns in Malaya are given in Fig. 5.

For the construction of these diagrams a method devised by THORNTHWAITE was used (28). The maximum storage capacity of the soil was arbitrarely fixed at 6 inches at all stations. This value corresponds to some estimates for tropical soils (29). It is possible that important local differences exist in this factor, but very little is known about the water-holding capacities of the various soil types in Malaya. To facilitate comparison between the different stations the samc value was used for all of them.

In these diagrams (Fig. 5) the "potential evaporation" is the evaporation observed at evaporation pans, or computed on the basis thereof. At evaporation pans there is always an unlimited supply of water available for evaporation and the observed values are the maximum amounts that can evaporate under the existing climatic conditions. But in nature, where there is often not sufficient water available to satisfy this potential evaporation, the "actual evaporation" can be considerably less. It is calculated by adding to the amounts of water supplied by rainfall those derived from the soil storage. Whenever the rainfall exceeds the potential evaporation there is a water surplus and the actual evaporation will be equal to the potential. The moisture deficit is simply the difference between potential and actual evaporation. It indicates the amount of water that could have been evaporated under prevailing conditions, but was not available in nature.

The diagrams show that the origin of the large water deficits during 1963 was in the months of February to April. The following four months (May–August) brought only modest water surpluses, which only in Kuala Lumpur and Mersing were large enough to replenish the soil-water storage. At the other stations the drought continued until August or September, but in Singapore only November brought a small water surplus and the end of the dry period.

A comparison of the moisture deficits for 1963 with the averages for the period 1957–1962 (Table 5) shows that 1963 was quite an exceptional year. Not only were the moisture deficits

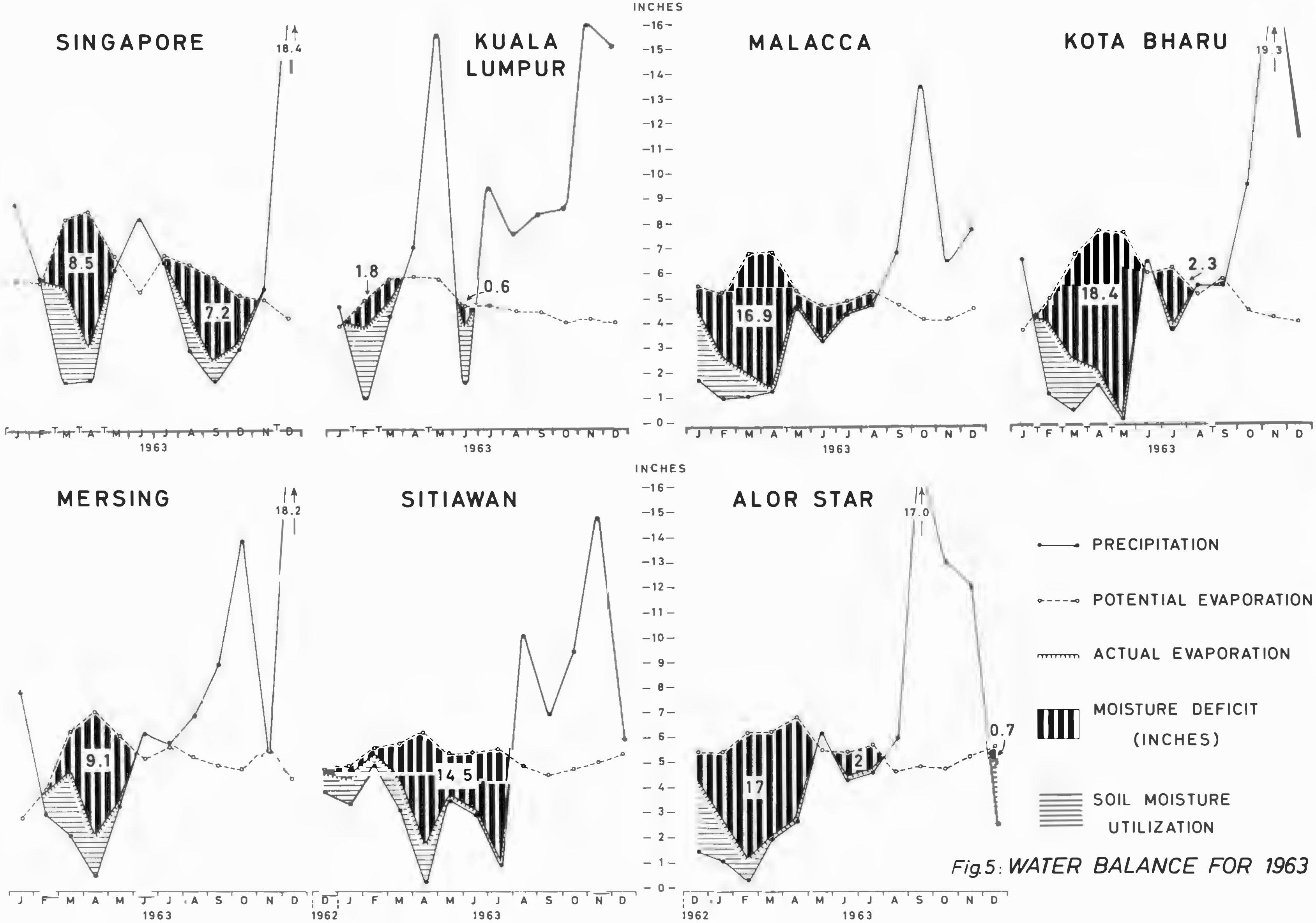

Fig. 5: WATER BALANCE FOR 1963

very large, but also persistent over long periods. The significance of these water deficits is evident: they represent a large proportion of the average annual precipitation.

Conclusion

The above analysis has clearly illustrated the shortcomings of a description of the rainfall conditions in Malaya which is based only on long-term averages. The actual conditions during 1963 differed from such a description to a considerable degree. The year 1963 was exceptional, as an unusually strong North East monsoon during February, March and April reduced the influence of the more important agencies of precipitation such as the air-stream boundary and local convection, during that period.

Rainfall conditions in Malaya during 1963 show how deceptive long-term averages can be. In Singapore, for instance, where according to averages a surplus of rainfall over evaporation occurs throughout the year the moisture deficit in 1963 lasted as long as eight months.

The high variability of rainfall has yet to be fully explained. Further extensive study of upper-air conditions might supply the solution, but the number of observations in this large area is still far too small to provide definite assessments.

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Table 5
Total annual Moisture Deficits

	Average for 1957–1962 Inches	*1963*		*Duration in Months*	
		Inches	In % of average total annual rainfall	Average for 1957–1962	1963
Singapore	0	15.7	16	0	4 + 4
Kuala Lumpur	0.1	2.4	3	1	2 + 1
Malacca	0.8	16.9	19	3	8
Kota Bharu	0.6	20.7	17	2	4 + 2
Mersing	0	9.1	8	0	4
Sitiawan	2.2	14.5*)	19	4	8*)
Alor Star	4.2	19.0*)	20	4	5*) + 2

*) Including December 1962.

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RAINFALL SEASONALITY IN THE TROPICAL SOUTHWEST PACIFIC [1])

With 5 figures and 6 maps (supplement V)

E. A. FITZPATRICK, DOREEN HART and H. C. BROOKFIELD

Zusammenfassung: Der jahreszeitliche Charakter der Niederschläge im Südwest-Pazifik.

Unter Verwendung der verfügbaren Niederschlagsmeßwerte von mehr als 1000 Stationen wurde eine Karte des durchschnittlichen jährlichen Niederschlages im Südwest-Pazifik gezeichnet und werden die meteorologischen und topographischen Faktoren des Niederschlages innerhalb dieses Gebietes diskutiert.

Für eine Zahl ausgewählter Stationen wurde außerdem der durchschnittliche monatliche Niederschlag genauer untersucht. Die Untersuchung ergab, daß mit wenigen Ausnahmen nicht mehr als zwei vergleichbare Zeitspannen notwendig sind, um einen hohen Prozentsatz der gesamten Variationsbreite der monatlichen Durchschnittswerte zu erklären. Die Auswertung der ersten und zweiten Periode vermittelt somit eine objektive Grundlage zur Abschätzung der durchschnittlichen Niederschläge für jede Woche. Diese Wochenschätzwerte sowie die Daten, die mit dem Höhepunkt und Tiefpunkt des jährlichen durchschnittlichen Niederschlagsablaufes zusammenfallen, wurden festgestellt und in die Karte eingetragen.

Die Wochenschätzwerte ergeben sieben ausgeprägte Typen des jährlichen Niederschlagsablaufes. Ihre geographische Verteilung und die allgemeinen Zusammenhänge zwischen der räumlichen Verteilung der Ablauftypen mit Zügen der pflanzlichen und menschlichen Ökologie des Gebietes werden aufgezeigt.

Das Ergebnis dieser Analysen macht die Lücken in unserem Verständnis der Zusammenhänge zwischen den allgemeinen geographischen, den meteorologischen und topographischen Zügen und dem festgestellten jahreszeitlichen Charakter des Niederschlages im Südwest-Pazifik deutlich. Der Mangel zureichender Meßdaten sowohl in Bodennähe als auch aus den oberen Luftschichten erschwert jedoch eine Vertiefung unserer Kenntnisse durch klimatologische Analyse in diesem Bereich.

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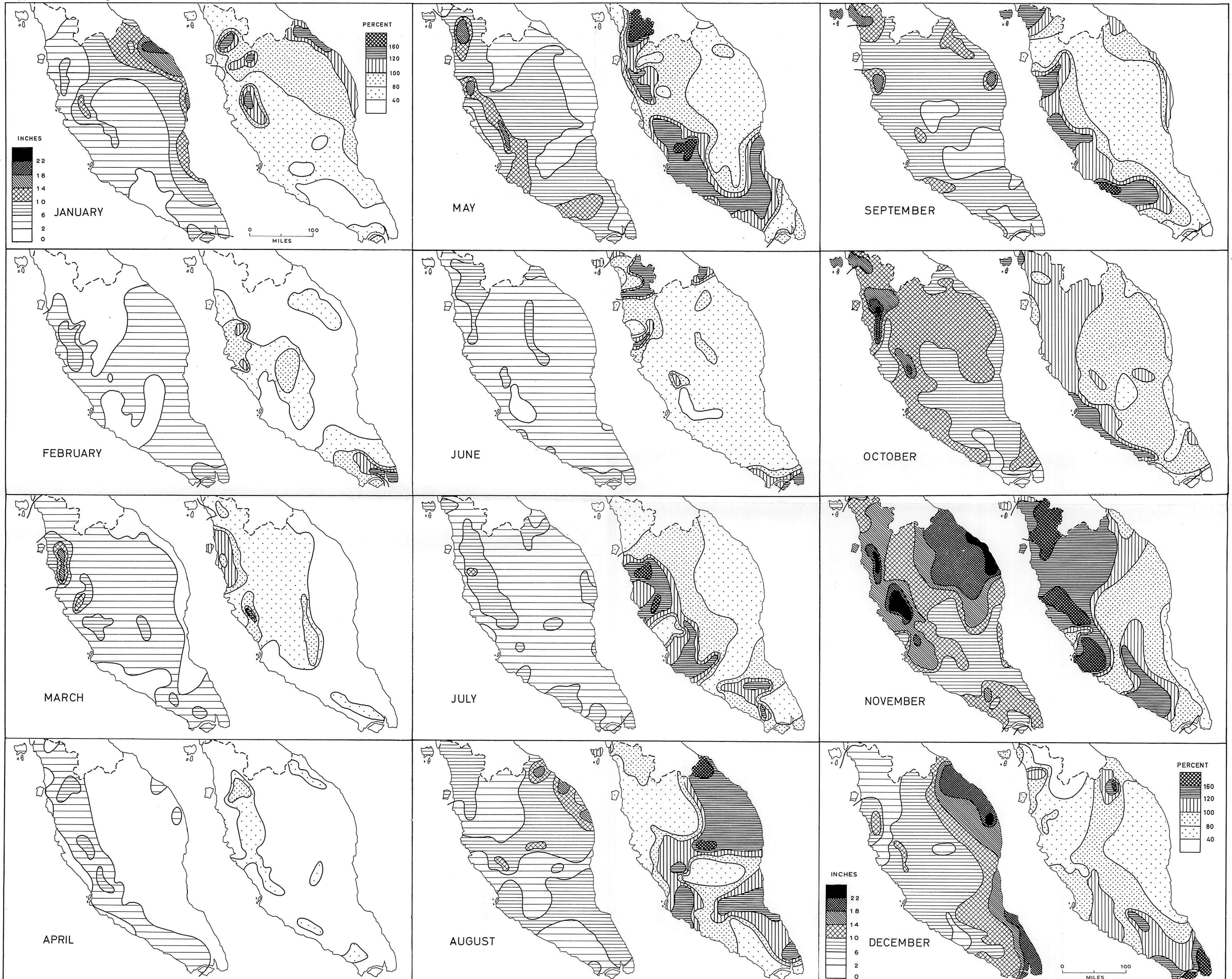
I. Introduction

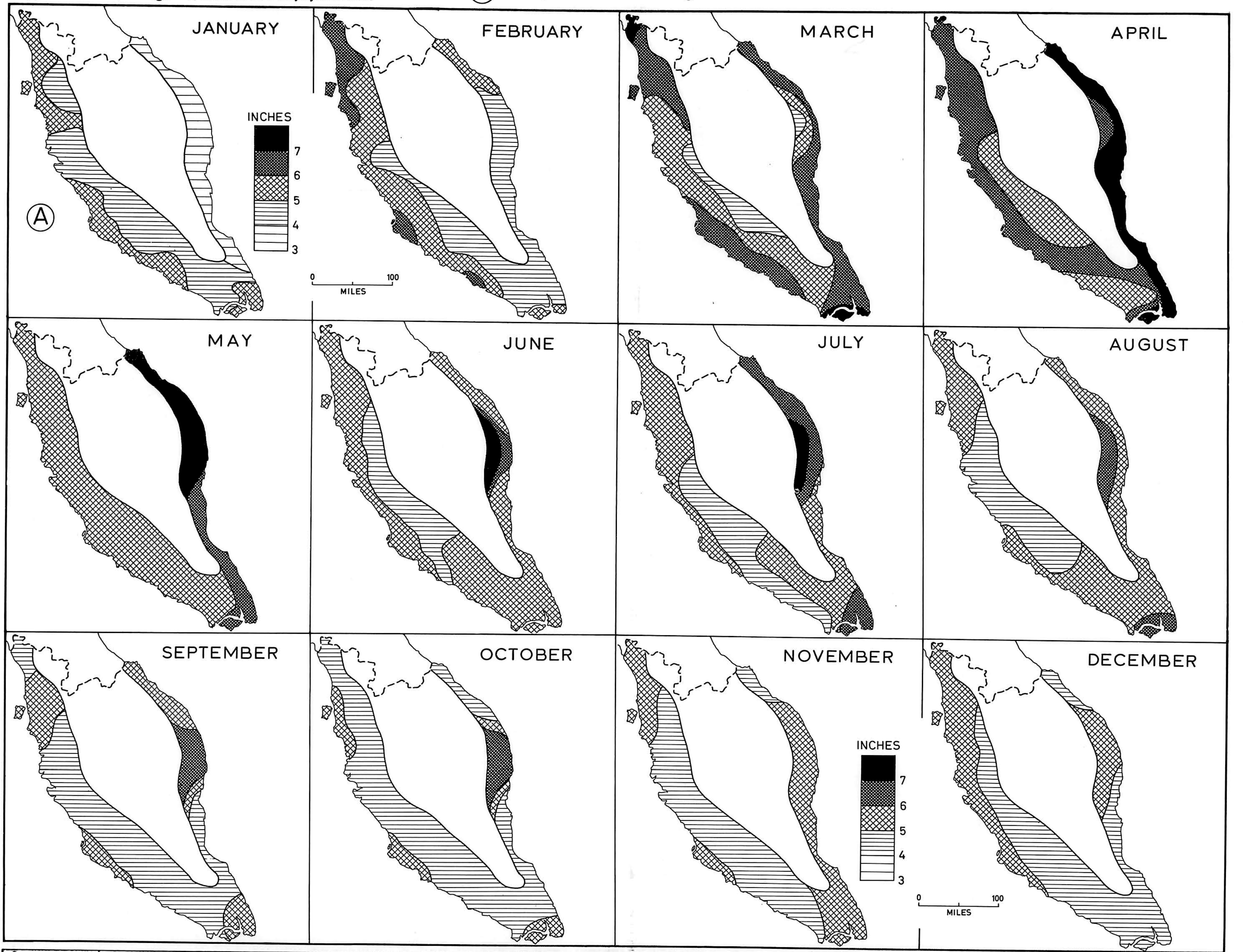
In the oceanic region north of Australia and New Zealand is a chain of mountainous islands that spans almost the full distance from the Equator to the Tropic of Capricorn. Together with the Indonesian archipelago lying immediately to the west, the northern part of this region is one of the wettest parts of the earth's surface; few areas fall more obviouslv into the 'Humid Tropics' by whatever means of classification we employ. Yet detailed rainfall data that have become available in recent years reveal a wide variety of climates, and in particular, a wide variety of rainfall regimes.

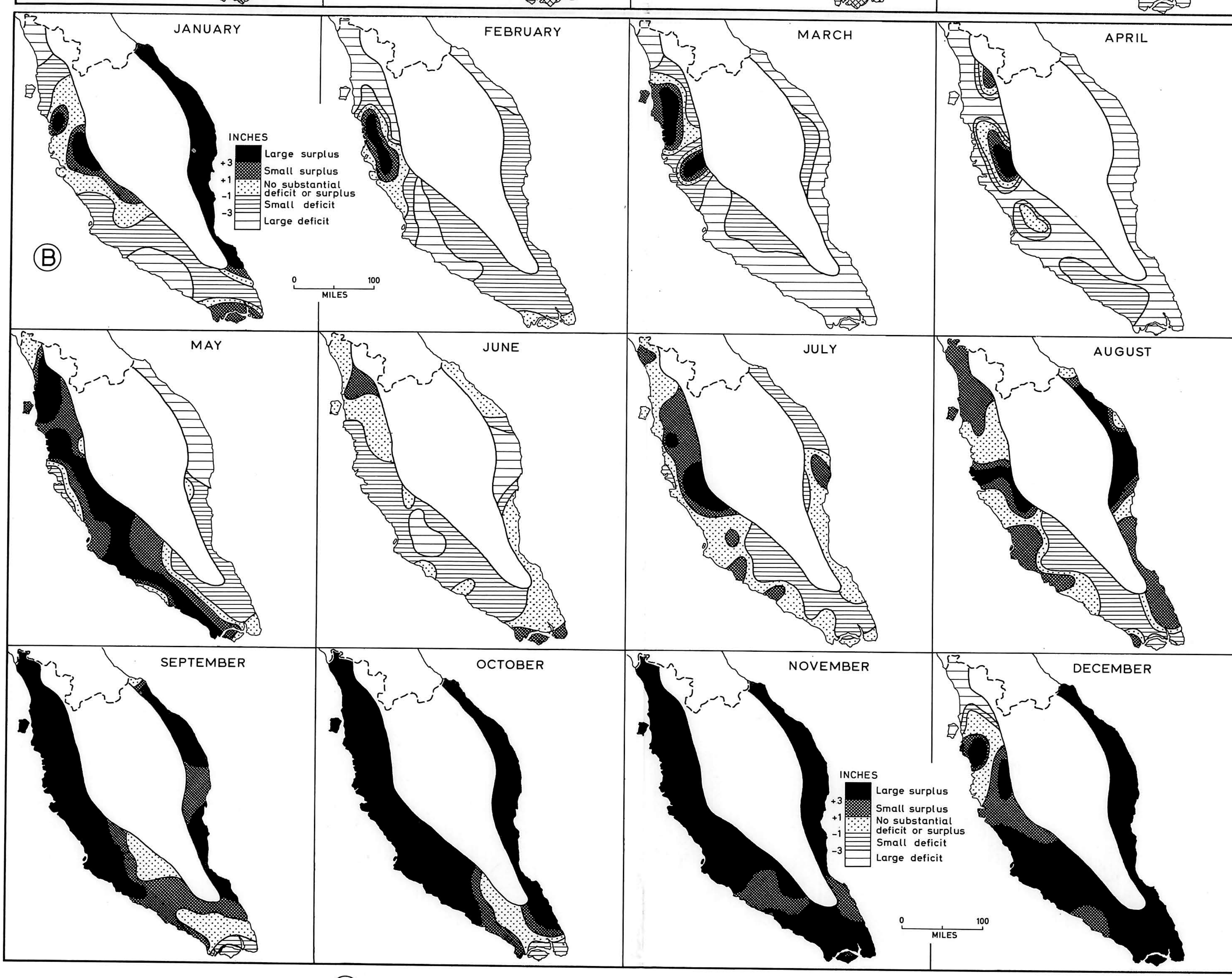
Supplement VI (Beilage VI), ERDKUNDE XX,3, Nieuwolt

Precipitation during 1963



Ⓐ Evaporation during 1963





Ⓑ Precipitation compared to evaporation during 1963